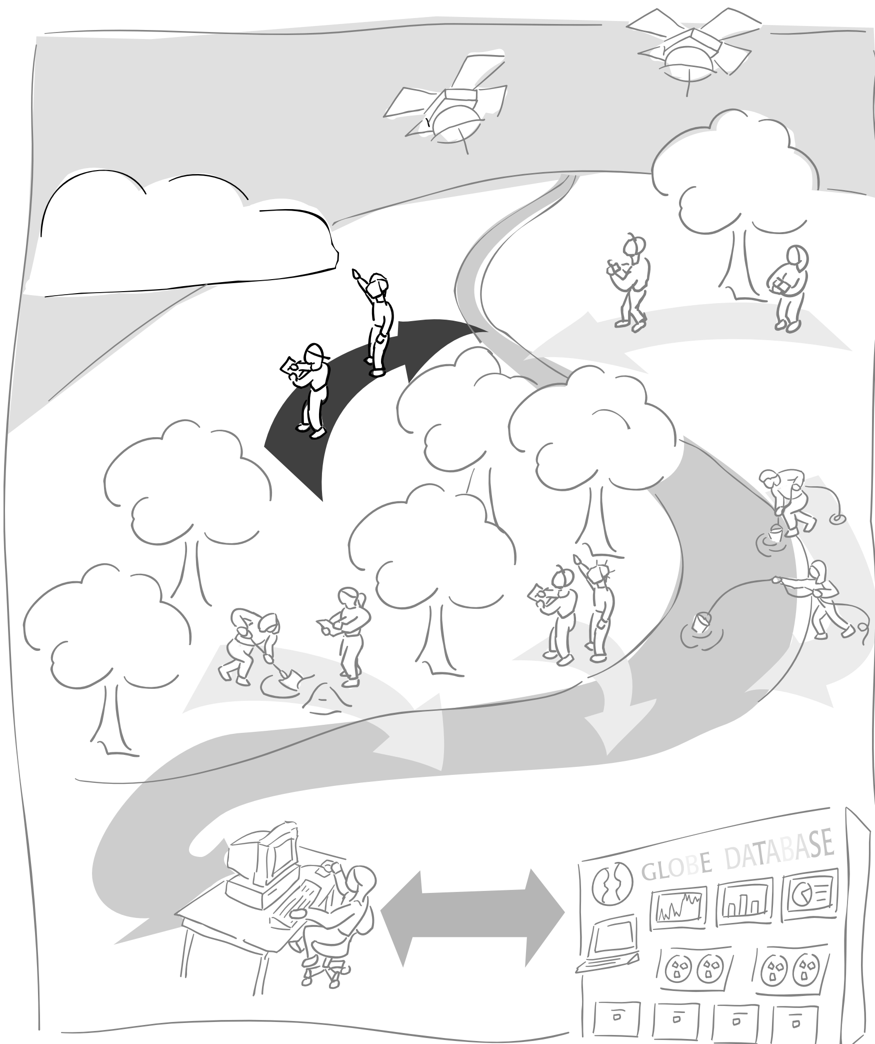
Earth System Science Investigation



A GLOBE® Learning Investigation

Earth System Science Investigation

Protocols

Daily, Seasonal Measurements

Basic
Budburst

Bi-weekly, Seasonal Measurements

Basic
Green-Up
Green-Down

Optional Measurements

Ruby-Throated Hummingbirds (daily or bi-weekly, seasonal)
Phenological Gardens (daily or bi-weekly, seasonal)

Suggested Sequence of Activities

- Read the Introduction to become familiar with seasons, phenology, and studying Earth system science at different space and time scales.
- If you want to do the *Phenological Gardens Protocol*, the best time to plant your garden is in the spring or autumn. You must wait a year to collect data.
- *What Can We Learn About Our Seasons*, *What Are Some Factors That Affect Seasonal Patterns*, *How Do Seasonal Temperature Patterns Vary Among Different Regions of the World* learning activities introduce students to characteristics and patterns of seasons.
- *Green-Up Cards, A Sneak Preview to Budburst,* and a *First Look at Phenology* learning activities set the stage for taking the phenology measurements.
- Choose one of the Phenology Protocols to start (*Green Down* or *Hummingbirds* in the fall; *Budburst*, *Green Up*, or *Hummingbirds* in the spring); Phenological Gardens throughout the year)
- *A Beginning Look at Photosynthesis* and *Investigating Leaf Pigments* learning activities help students better understand the process of photosynthesis.
- *Global Patterns in Green-Up and Green-Down* and *Limiting Factors in Ecosystems* allow students to explore global trends in green-up and green-down and to explore why these patterns occur in different ecosystems.
- *Modeling the Reasons for Seasonal Change* and *Seasonal Change on Land and Water* learning activities helps students understand factors that cause seasonal patterns.
- *Connecting the Parts of the Study Site, Representing the Study Site in a Diagram, Using Graphs to Show Connections, Diagramming the Study Site for Others*, and *Comparing the Study Site to One in Another Region* learning activities allow students to explore Earth system connections at the local scale.
- *Defining Regional Boundaries* and *Effects of Inputs and Outputs on a Region* learning activities allow students to explore Earth system connections at the regional scale.
- *Your Regional to Global Connections* and *Components of the Earth System Working Together* learning activities allow students to explore Earth system connections at the global scale.

Table of Contents

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

** Separate print version available on request to schools in the areas where the protocol may be . conducted. The protocol and related material are also available in the e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

*Learning Activities: Exploring the Connections**

Appendix

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction

Why Study Earth System Science?

Perceiving Earth as a system begins when we first feel warmth from sunshine or get wet standing in the rain. Understanding Earth as a system – Earth System Science – requires a quantitative exploration of the connections among all parts (atmosphere, hydrosphere, lithosphere, and biosphere) of the system. The measurements of the GLOBE Program provide students with the means to begin this exploration for themselves.

The processes comprising the global environment are interconnected. Many of the major environmental issues of our time have driven scientists to study how these connections operate on a global basis – to understand the Earth as a system.

Studies of the stratospheric ozone layer involve questions about the processes which create and destroy ozone. Scientists have learned that ozone, a chemical primarily found in a layer centered about 25 km above Earth's surface, is connected to biological activity happening below Earth's surface. Different chemicals, present in the air in trace amounts, control the abundance of ozone in the atmosphere. The sources of these trace constituents include microorganisms in the soil and water, land plants, and even some animals.

Scientists studying climate changes are also interested in the connections between the different Earth processes. Some of the trace gases in the atmosphere make it more difficult for heat (infrared radiation) to escape from the Earth's surface to space. The amounts of these greenhouse gases found in the atmosphere are tied to the physical, chemical, and biological processes taking place in soil and water and on land. They are also influenced by the circulation of the oceans and atmosphere. To predict the future course of the climate we need to understand this detailed fabric of connections.

Ecologists study the way in which the living and non-living components of an ecosystem interact. Individual organisms and species compete and cooperate with one another. In some cases, interdependence is so strong that different plants and animals cannot reproduce or even exist without each other. There is a web of life with extensive recycling of nutrients, and each organism plays a role. If one component of the ecosystem is changed the effects ripple through the system.

Scientists do not know all the Earth system connections yet, but they keep working to gain a more complete understanding. GLOBE students can help through data collection and student research. GLOBE students and scientists working together will improve our understanding of the Earth system. As students conduct the full range of GLOBE measurements (perhaps spread over several school years in multiple grades), they should gain a perception that the environment is the result of an interplay among many processes that take place locally, regionally, and globally on time scales ranging from seconds to centuries. This is a key GLOBE lesson. The learning activities in this chapter help students learn this as they study annual variations in environmental parameters (the *Seasons and Phenology* section) and examine the connections among the various phenomena measured in GLOBE on local, regional, and global spatial scales (the *Exploring the Connections* section).

In addition to learning activities, there are phenology protocols within the *Seasons and Phenology* section. Phenology is the study of living organisms' response to seasonal changes in their environment. Change in the period between green-up and senescence, often synonymous with the growing season, may be an indication of global climate change. Broad-area estimates of the lengths of growing seasons are primarily based on satellite data. However, remote sensing estimates from satellites are not exact because the actual behavior of the plants must be inferred from the collective appearance of their foliage. GLOBE student observations, the only global network of ground-based plant phenology observations, will help scientists validate their estimates of global greenness values that they derive using satellite data. Monitoring the length of the growing season is important for society so that it can better adapt to variations in the length of the growing season and to other impacts of climate change, which may affect food production, economic growth, and human health.

The Big Picture

The planet we call Earth is made up of five 'spheres', the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere, connected to each other in a complex web of processes. See Figure EA-I-1. The atmosphere consists of the gases and particles suspended in the air. The oceans, inland water bodies, ground water, and ice sheets (cryosphere), comprise the hydrosphere. The lithosphere refers to the solid earth; the core, mantle, crust, and soil layers (pedosphere). The places on Earth where organisms live are collectively known as the biosphere. Instead of focusing on the individual parts of the Earth, Earth system scientists use chemistry, biology, and physics to study the cycles that connect these spheres with each other and with the energy from the sun, which ultimately drives almost all of these processes.

The major cycles that connect the different parts of the Earth are the energy cycle (see Figure EA-I-2), the water cycle (hydrologic cycle, see Figure EA-I-3), and the cycles of important individual elements (e.g., carbon, nitrogen, see Figure EA-I-4). Each cycle is made up of *reservoirs,* places where energy, water, and elements are stored for a period of time (e.g., chemical energy, sea ice, oceans, carbon dioxide), *fluxes,* the movement of matter from one reservoir to another (e.g., precipitation, transpiration, ocean currents, wind, river flow) and processes that change the form of energy, water, and elements (e.g., photosynthesis, condensation, fire). Every GLOBE measurement is designed to help Earth System scientists in their goal of determining the sizes of Earth's reservoirs and the rate of fluxes into and out of these reservoirs.

Energy from the sun flows through the environment, heating the atmosphere, the oceans, and the land surface, and fueling most of the biosphere. See Figure EA-I-2. Differences in the amount of energy absorbed in different places set the atmosphere and oceans in motion and help determine their overall temperature and chemical structure. These motions, such as wind patterns and ocean currents redistribute energy throughout the environment. Eventually the energy that began as sunshine (short-wave radiation) leaves the planet as Earth shine (light reflected by the atmosphere and surface back into space) and infrared radiation (heat, also called long wave radiation) emitted by all parts of the planet which reaches the top of the atmosphere. This flow of energy from the sun, through the environment, and back into space is a major connection in the Earth system; it defines Earth's climate.

Water and chemical elements are cycled through the environment. Water melts, evaporates, condenses, and freezes, and is moved from place to place in the atmosphere, the oceans, across the land surface, and through soil and rocks. See Figure EA-I-3. Each of the chemical elements undergoes chemical reactions, but the total amount of each on Earth remains essentially fixed. In this way, the environment consists of a set of cycles for water, carbon, nitrogen, phosphorous, etc. Since the cycles of the elements involve life, chemicals, and the solid Earth, they are collectively known as *biogeochemical cycles.* Figure EA-I-4 shows one of these, the carbon cycle.

Figure EA-I-1: Schematic Diagram of the Earth System from the Center of the Earth to 480 km up into the

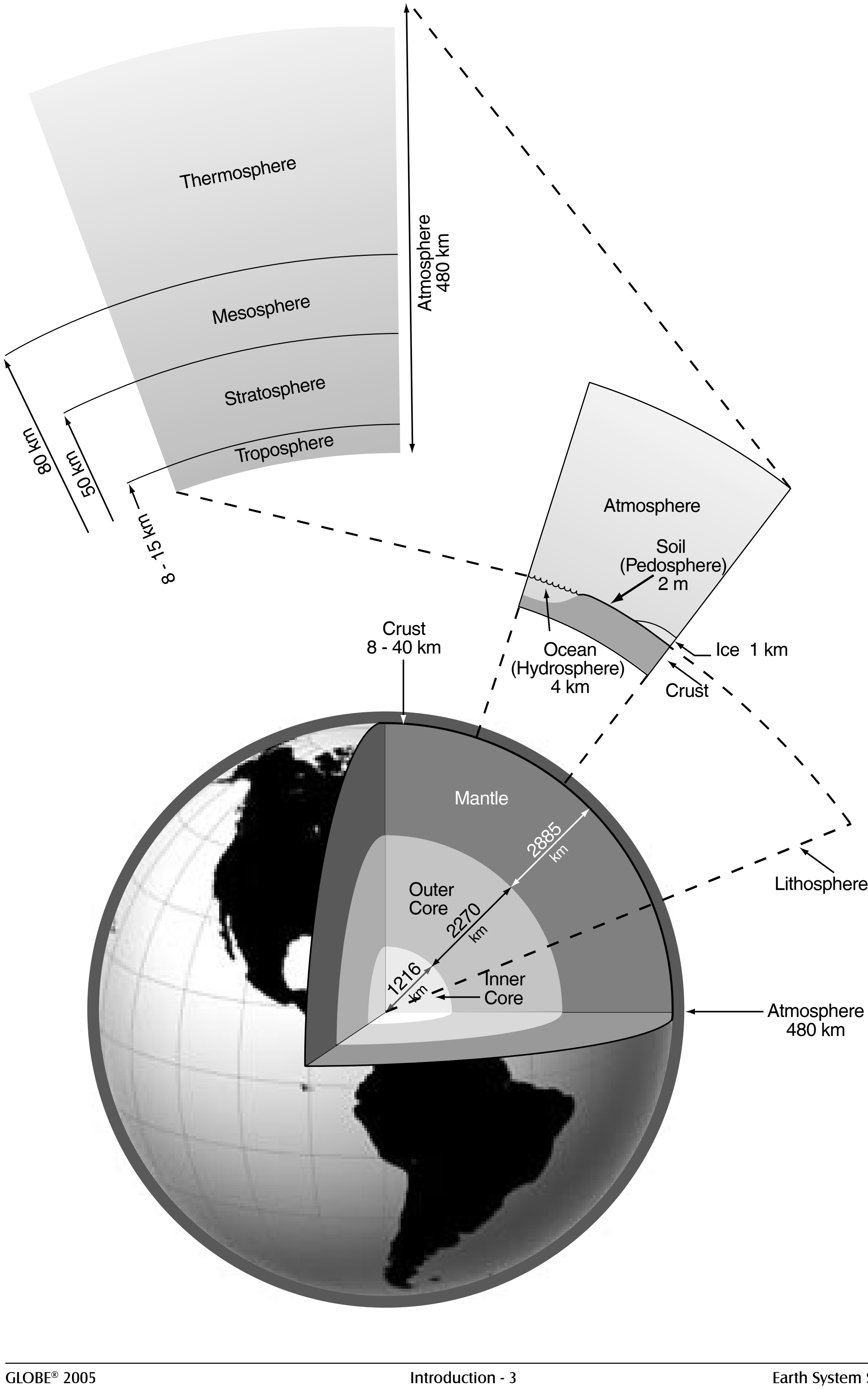


Figure EA-I-2: Schematic Diagram of the Earth's Energy Budget

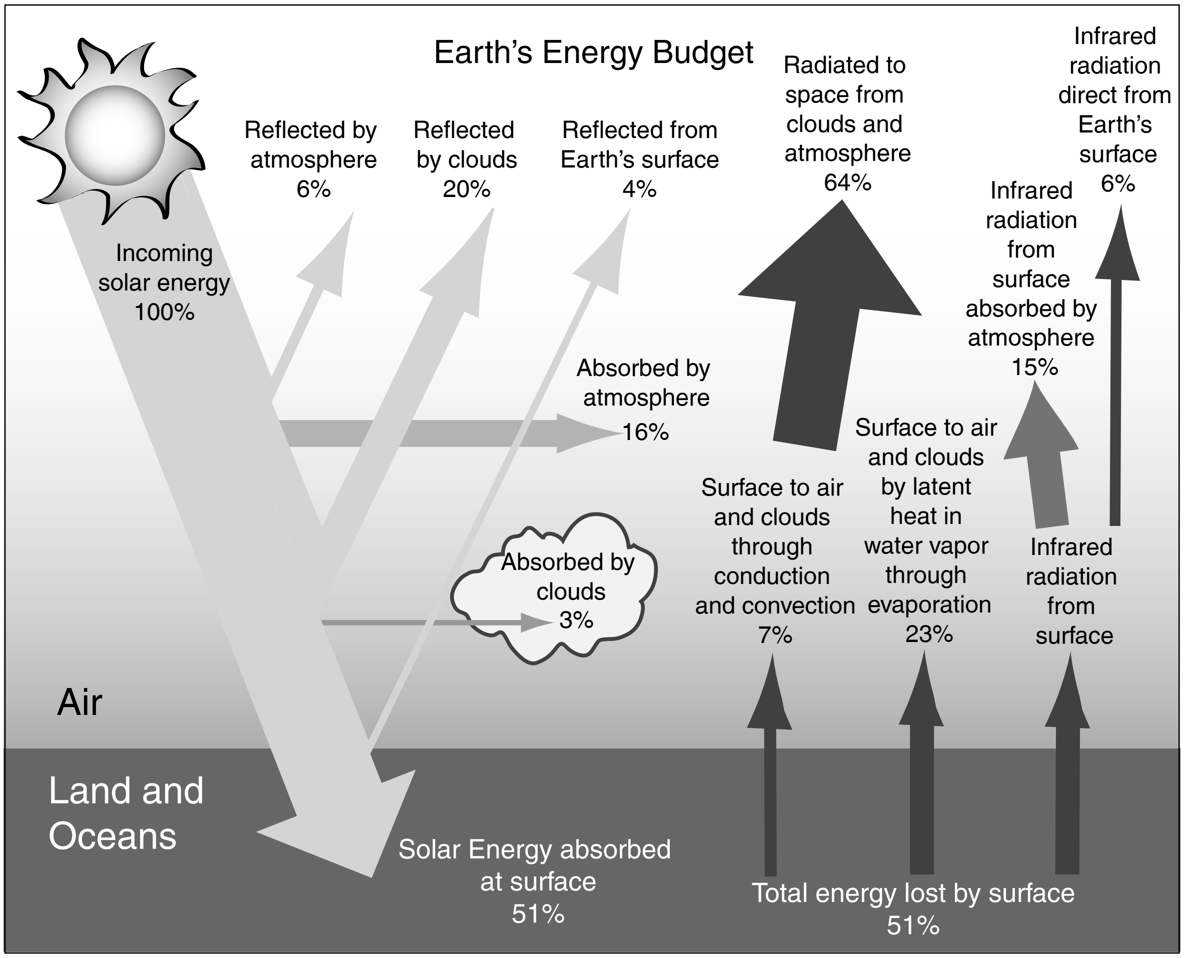


Figure EA-I-3: The Hydrologic Cycle

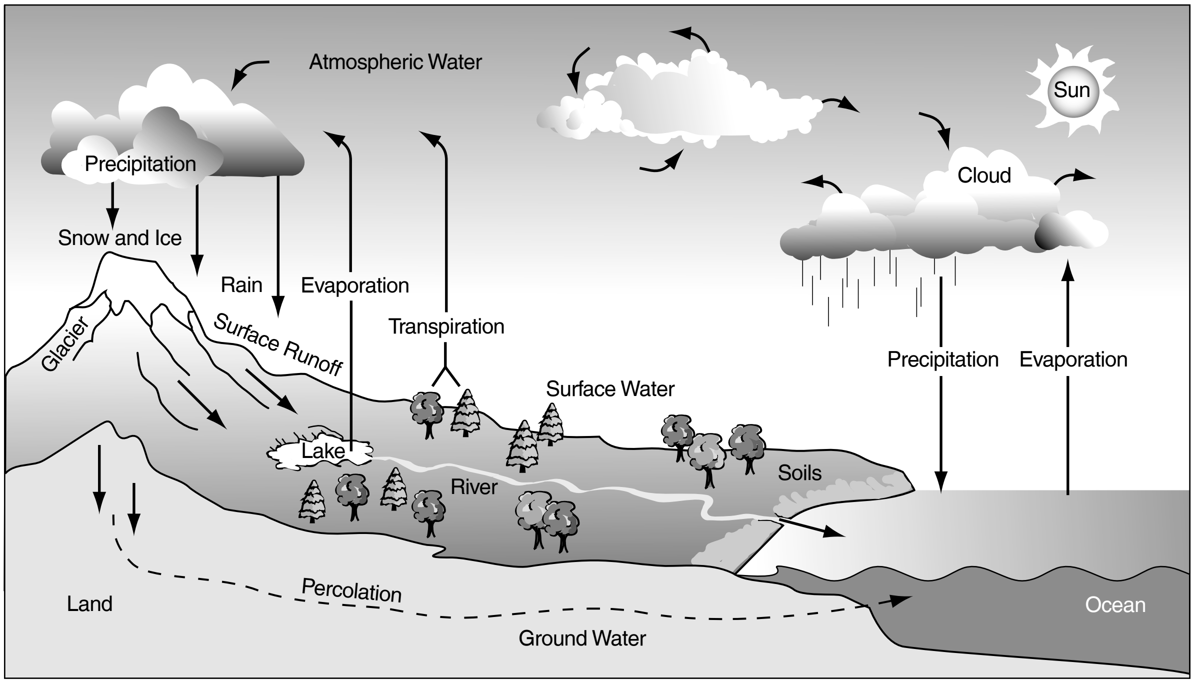
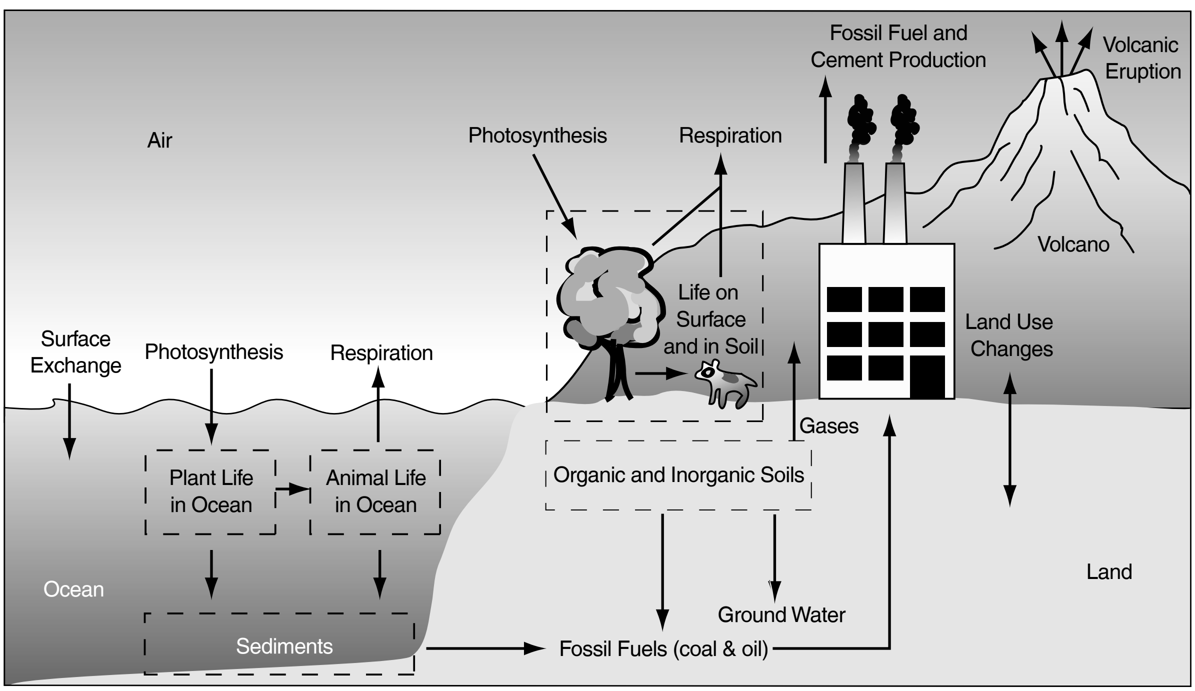


Figure EA-I-4: The Carbon Cycle



Components of the Earth System

The GLOBE program has students take measurements of many parts of the Earth's systems. The table below indicates where the GLOBE investigations lie with the components of the Earth system.

Components of the Earth System	**GLOBE Investigations**
Atmosphere (Air)	Atmosphere Investigation
Oceans and Fresh water bodies	Hydrology Investigation
Cryosphere (ice)	Atmosphere Investigation (solid precipitation) Hydrology Investigation (frozen water sites)
Soil	Soil Investigation
Terrestrial (land) vegetation	Land Cover Investigation Earth as a System Phenology Investigation

Cycles of the Earth System

In the environment, energy can be in the form of radiation (solar or short-wave radiation and infrared or long-wave radiation), sensible heat (thermal energy), latent heat (heat released when water goes from the gas to the liquid or solid state), kinetic energy (energy of motion including winds, tides, and ocean currents), potential energy (stored energy), and chemical energy (energy absorbed or released during chemical reactions). Scientists want to know, model and predict the amount of energy in all of its forms in each component of the Earth system, how it is exchanged among the components, and how it is moved from place to place within each of the components.

The energy cycle is intertwined with the hydrologic cycle. Some of the energy in the sunlight reaching Earth's surface causes evaporation from surface water and soils. The atmosphere transports the resulting water vapor until it condenses in clouds, releasing the latent energy that evaporated the water. Water droplets and ice particles in clouds grow in size until they form precipitation, falling to the surface as rain, snow, sleet, or hail. Once the precipitation falls, the water can remain frozen on the surface to melt at a later time, evaporate again into the atmosphere, fill spaces in the soil, be taken up by plants, be consumed by animals, leach through the soil into groundwater, run off the land surface into rivers, streams, lakes and ultimately into the oceans or become part of a surface water body. Snow and ice reflect more sunlight back to space than ocean water or most other types of land cover, so the amount of snow or ice covering Earth's surface affects the energy cycle.

Together, the combined energy and hydrologic cycles affect the biogeochemical cycles. In the atmosphere, chemical reactions driven by sunlight create and destroy a rich mixture of chemicals including ozone. Some of these chemicals combine with water to form aerosols –liquid and solid particles suspended in the air. Atmospheric chemicals and aerosols become incorporated in water droplets and ice crystals and are carried from the atmosphere to the surface by precipitation. Microorganisms in the soil and surface waters, plants, and animals all take in chemicals from the air and water around them and release other chemicals into the atmosphere, fresh water bodies, and oceans. Winds enhance evaporation of water from the surface and blow fine grain particles into the air where they are suspended as aerosols. Agricultural and industrial activities also input and remove energy, water, gases, and particles from surface waters, soil, rocks, and air. The quantity and distribution of gases such as water vapor, carbon dioxide, nitrous oxide (N_2O), and methane in the atmosphere determine how infrared radiation is absorbed and transmitted between Earth's surface and space. This in turn affects the temperature at the surface and throughout the atmosphere. There are many other ways in which the energy, water, and biogeochemical cycles interact and influence our environment, far more than can be described here.

How GLOBE Measurements Contribute to Earth System Studies

GLOBE measurements of the temperature of air, water bodies, and soil help track the energy cycle. GLOBE students also measure cloud cover, cloud type, aerosols, water transparency, and land cover.

Each of these observations helps scientists determine what happens to the solar radiation (sunlight) and the thermal infrared radiation originating on Earth (heat). How much sunlight is reflected or absorbed by clouds or Earth's surface? How much out-going infrared radiation is absorbed by the atmosphere and how much is re-radiated back downward?

GLOBE measurements of liquid and solid precipitation, relative humidity, soil moisture, land cover, and canopy and ground cover and the identification of the dominant and codominant species of trees help track the hydrologic cycle. Knowing the characteristics of the top meter of soil and its infiltration properties enables scientists to calculate how water will pass into and through the soil; soil bulk density and particle density determine how much water can be stored in the soil. Measurements of the surface temperature of a water body and of soil moisture and temperature enable estimation of evaporation rates. How much rain falls on Earth? Is the hydrologic cycle becoming more intense? Are the various fluxes in the hydrologic cycle increasing?

GLOBE observations contribute to the study of the biogeochemical cycles. Measurements of the pH of precipitation, soil horizons, and surface waters are fundamental because pH influences how different chemical elements interact with water flowing through the environment. Lowering pH can mobilize different chemicals from the surfaces of rocks and soil particles. Living plants are a significant reservoir in the carbon cycle. Measurements of the mass of dried grasses and the circumference and height of trees enable estimation of how much carbon is stored in the living biomass of a forest or grassland. As carbon is added to the atmosphere, how much is taken out by terrestrial vegetation?

Open versus Closed Systems

If you look at Earth from outer space, the Earth is an *almost* closed system. A closed system is one in which no matter enters or leaves. (An *isolated system* is one in which no matter or energy enters or leaves.) Other than the transfer of some gases and particles entering Earth's atmosphere, the components remain on Earth without new additions. When studying Earth as a whole, you usually do not need to consider the effects of inputs and outputs to the Earth system except for the energy from the sun.

Smaller systems can be nested within larger systems. For instance, you can study a watershed — the land area which all drains into a common water body. Watersheds come in a variety of sizes with smaller ones combining to form larger ones. For example, you could study the entire area which drains into the Arctic Ocean, or focus only on the MacKenzie River basin in Canada, or on just the Liard River, a tributary of the MacKenzie. Where you define the boundaries of your system, as a watershed, depends on the questions being asked. These concepts will be developed more in *Exploring the Connections*.

Any system within the Earth system, such as a watershed, is considered an open system. Water and chemicals as well as energy enter and leave the boundaries of the system. Still, the components of this open system may be more closely connected to one another than they are to exchanges between the system and its surroundings. The inputs and outputs may be important for understanding the dynamics of the system you are studying.

Scales of Space and Time

All the processes of the Earth system occur on specific space and time scales. Some occur on a scale so small that our eyes cannot see them, while other phenomena cover an entire continent or the whole planet. The time scales for different phenomena vary tremendously as well. Some atmospheric chemical reactions happen in fractions of a second. The formation of soil with its interplay of physical, chemical, and biological characteristics happens locally over many years (generally at a rate of 1 cm of depth per century). Major weather systems including hurricanes usually develop and dissipate on time scales of one to two weeks and cover hundreds of kilometers.

Parts of the various cycles of the Earth system can be measured and understood locally on relatively short time scales, seconds to days; in other cases, one must try to characterize the whole globe for decades to test theories, understand processes, and gain overall knowledge. Let's consider one example of each situation:

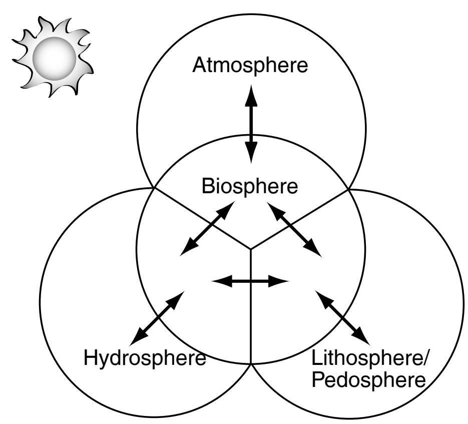
1. **The balance in the amount and flow of water in a small watershed.**
   We can sample the input of water to the surface by measuring precipitation at one or more sites (the more sites, the better the estimate will be). The evaporation of water can be calculated from temperature measurements of the surface soil and water and knowledge of the surface soil moisture and particle size distribution or texture. The transpiration of water by trees and other plants can be estimated by mapping the land cover, measuring canopy and ground cover at a number of sites, and identifying the dominant species of trees in the forests and woodlands. Measurements of soil moisture and the levels of streams, lakes, and rivers tell how much water is stored in the watershed (discounting aquifers or other major underground water bodies). The level of the stream or river through which water flows out of the watershed is an indication of how fast this flow is. The inputs and outputs must balance with the change in the amount of water stored. Most of the needed measurements are included in the GLOBE protocols and the others can often be obtained from other sources or measured with help from local scientists.
2. **Understanding the El Niño/Southern Oscillation (ENSO)**
   The warm episodes of the ENSO occur at irregular intervals of two to seven years. Changes develop across the entire equatorial Pacific basin and effects have been observed developing as much as six months later throughout the temperate zones of both hemispheres. Small remnant phenomena from warm events have been observed by satellites as much as ten years later. To thoroughly characterize this phenomenon and its effects we must take data for many years on a global scale and look for connections, causes, and consequences. Predictions based on an overall understanding of the ENSO can be examined locally using data records covering many months including the data sets collected and reported as part of GLOBE. GLOBE student data of air temperature and precipitation can be compared with model predictions of ENSO effects to help determine the adequacy of our current understanding and modeling abilities.

Key Concepts

As discussed in the previous pages, when studying Earth as a system, there are a few key concepts to understand. These are:

- The Earth is a system made up of components.
- Energy, water, and the chemical elements are stored in various places and forms and are transported and transformed by various processes and cycles.
- Connections among phenomena can be traced through the energy, hydrologic and biogeochemical cycles.
- Phenomena happen on a range of time and spatial scales.

Four Major Components of the Earth System



Note: See *Diagramming Earth as a System* in *Exploring the Connections Introduction.*

The Earth as a System

The Seasonal Cycle

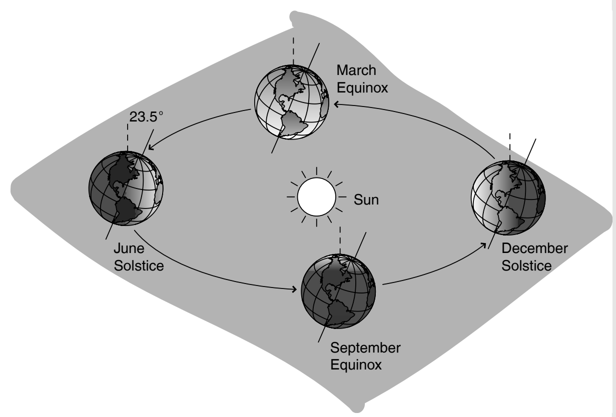
The Seasonal Picture: Why are there seasons?

Earth's seasons change in a regular fashion and bring a rhythm to our lives. Whether it is the arrival of winter snows, monsoon rains, or summer heat, our environment changes constantly, and these profound changes occur over relatively short time periods. That they recur in predictable ways helps make such huge, complex changes comprehensible. Many ancient civilizations observed that the Sun's position in the sky changed throughout the year and were able to construct calendars and make predictions based on their observations, which they used for agricultural and religious purposes.

All seasonal changes are driven by shifts in the intensity of sunlight reaching Earth's surface (*insolation*). More energy per unit area leads to higher temperatures, which results in more evaporation, which produces more rain, which starts plants growing. This sequence describes Spring for many mid-latitude climates. Since visible light is the main form of solar energy reaching Earth, day length is a reasonably accurate way to gauge the level of insolation and has long been used as a way to understand when one season ends and the next one begins. The first day of summer, (*summer solstice*) is the longest day of the year. Winter starts on the shortest day of the year, (*winter solstice*). The first days of spring and fall are when the day and night are of equal length — roughly 12 hours each. These days are named *vernal* and *autumnal equinoxes*.

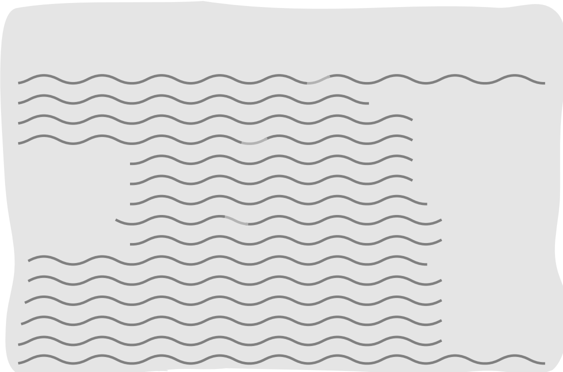
The changing day length results from the Earth's axis of rotation being inclined 23.5˚ with respect to the plane of its orbit around the sun. Figure EA-I-5 shows the inclined Earth at different positions in its orbit. Notice how at the solstice positions, each pole is tilted either toward or away from the Sun. The pole inclined toward the Sun receives 24 hours of sunlight, and the one inclined away is in Earth's shadow and experiences 24 hours of darkness. At the equinox positions, Earth is inclined in a way so that each pole receives equal amounts of insolation. This discussion focuses on the poles because they experience the greatest extremes of insolation. Because of the inclination of Earth's axis, insolation levels at every point on Earth change constantly. We call the aggregate effects of these changing levels *seasons*.

Figure EA-I-5: Tilt of the Earth's Axis



The tilt in Earth's axis of rotation has an additional effect, which amplifies the length of day effect. At every latitude, the Earth's surface is at a different angle with respect to the incoming sunlight. Look at Figure EA-I-6. When the surface is perpendicular to the sunlight, the sun is straight overhead, and the amount of sunlight striking a fixed area is at its maximum. As the sun moves lower in the sky and the angle at which sunlight strikes the ground decreases, the intensity of sunlight striking the same area gets smaller. In the summer, the sun is closer to being straight overhead at local solar noon than in the winter except close to the equator. So, not only is the day longer in summer than in winter, but the sun delivers more energy to each unit of area of Earth's surface in the hemisphere where it is summer.

Figure EA-I-6: How Latitude Affects the Amount of Incoming Energy from the Sun

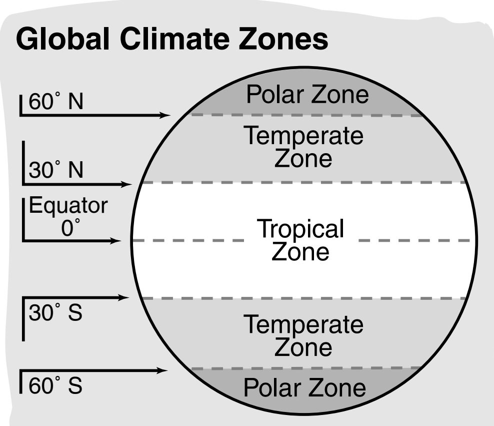


Factors Influencing Local Seasonal Patterns

Latitude

Figure EA-I-7 shows how insolation levels vary with latitude throughout the year. Because of this variation, latitude has a powerful influence in determining seasonal conditions and the annual patterns of environmental and climatic parameters such as precipitation and temperature. Because of the differences in the duration and directness of insolation, the world can be divided into the zones shown in Figure EA-I-8. The same season can be quite different in the Tropical, Temperate and Polar zones.

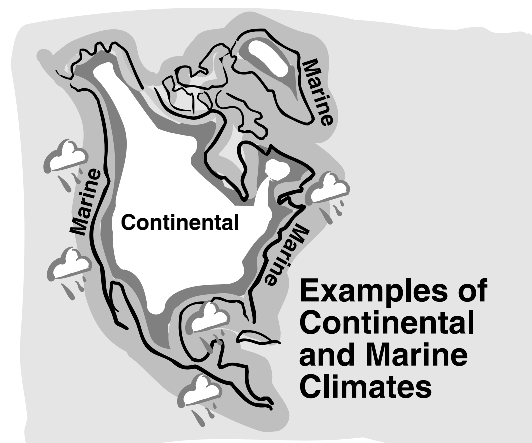
Figure EA-I-8: Approximate Global Climate Zones



Continental and Marine Climates

Climate also varies dramatically depending on the amount of water in the environment. When sunlight strikes the surface of water, four things keep the water surface from warming as much as the land surface. First, the specific heat or the energy it takes to heat one gram of water one K is 1 cal g^{-1} K^{-1} compared to 0.4 cal g^{-1} K^{-1} for soil. It therefore takes 2.5 times the energy to heat water by 1K than it takes to heat soil 1K. Second, some of the sunlight penetrates many meters into the water column. This spreads the incoming energy down into the water body and the surface is less warmed. Also, colder water from lower depths mixes to some extent with the surface water and moderates its temperature changes. Third, winds produce movement in the surface waters which causes a mixing of heat throughout the surface layer. Fourth, as surface water warms, evaporation increases. Evaporation cools the surface and so the temperature of the water surface responds less to solar heating than the land surface. Land which is near large bodies of water that do not freeze in winter has a marine climate. This features larger amounts of moisture and smaller temperature changes from summer to winter than a continental climate. The size of a continent affects both the temperature range and the amount of moisture in the interior – the larger the continent, the further away the ocean and the larger the difference between summer and winter.

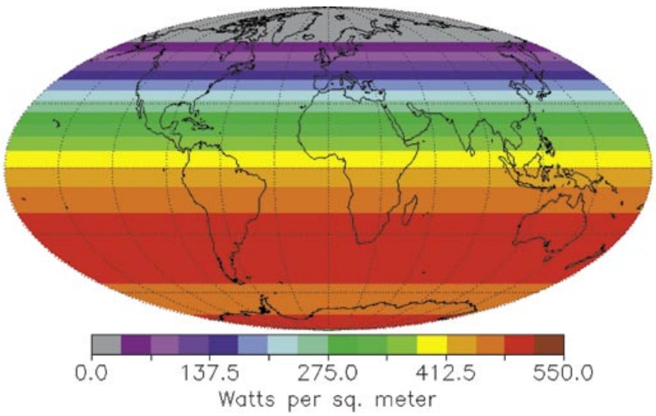
Figure EA-I-9: Continental and Marine Climates



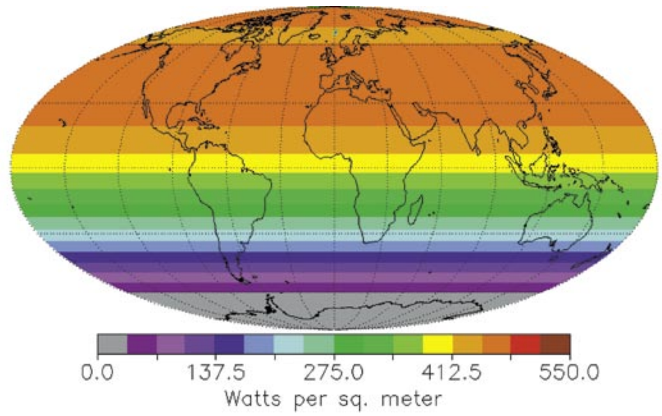
Wind Direction

The direction of the prevailing winds also affects local climate. If an area is downwind of the ocean (the west coasts of continents in mid-latitudes) the climate is strongly affected by the presence of the ocean as described above. If the winds are blowing from the interior of the continent, then they tend to be dry and to bring with them the larger contrasts in summer and winter temperatures.

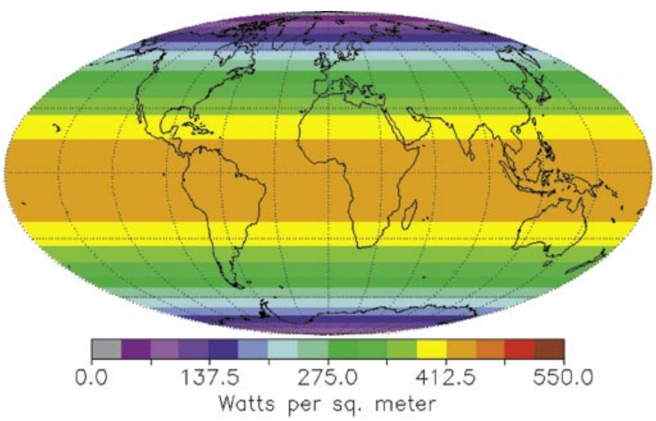
Figure EA-I-7: Incoming Solar Radiation Throughout the Year



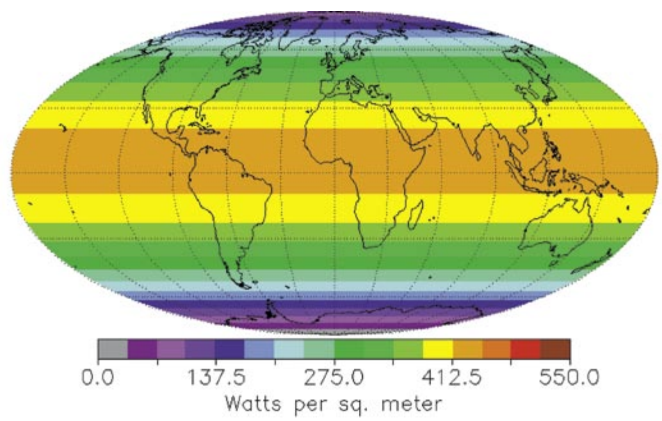
January Solar Radiation



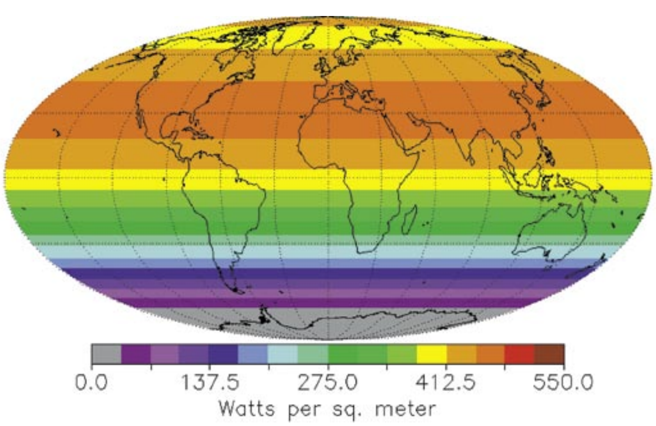
July Solar Radiation



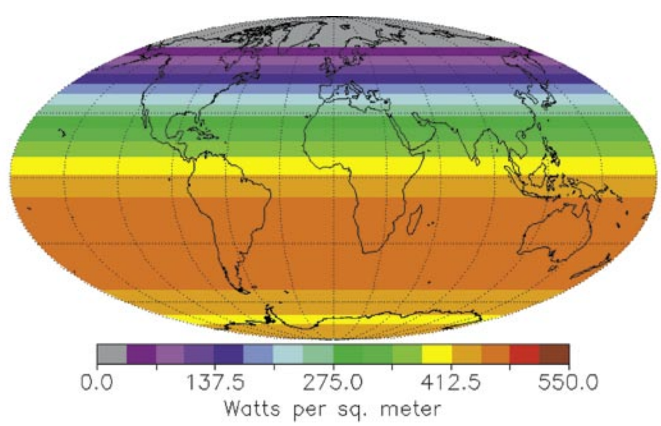
March Solar Radiation



September Solar Radiation

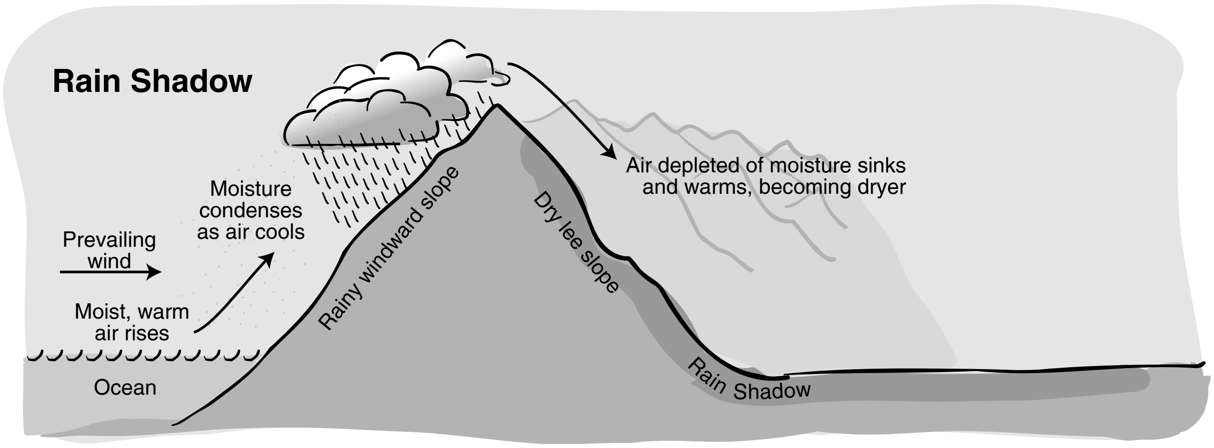


May Solar



November Solar Radiation

Figure EA-I-10: Mountain Producing a Rain Shadow Effect



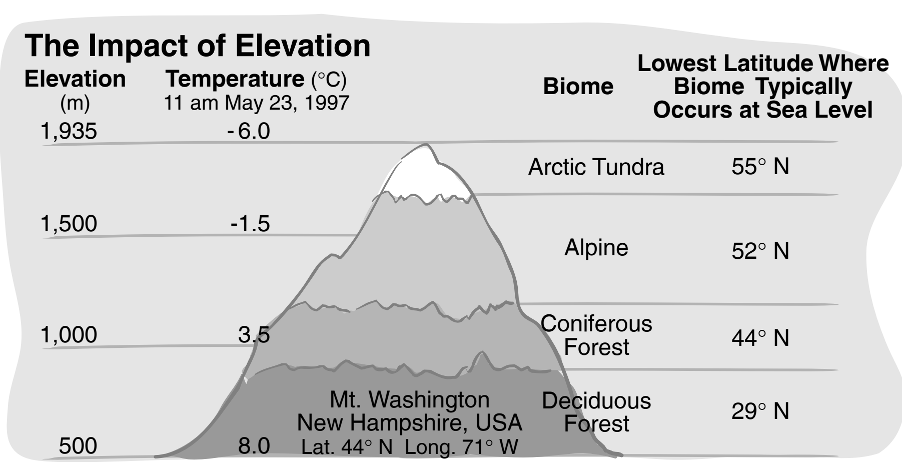
Areas in the high latitude parts of the temperate zones and downwind of lakes receive large amounts of lake-effect snow while the lakes are unfrozen. Generally, prevailing winds connect the local climate with that upwind. Seasonal changes in prevailing wind direction can make seasonal contrasts greater or smaller.

Geographical Features

Geographical features have profound impacts on the climate of nearby regions. For example, mountains can cause moist air to rise and precipitate out almost all of its moisture. When dry air descends behind the mountain, it lacks enough moisture to provide much precipitation. The mountains create a rain shadow. See Figure EA-I-10. Many deserts are found in such rain shadows. In addition to arid land, typical desert regions lack the atmospheric moisture that acts as insulation between the Earth's surface and space (water is the major greenhouse gas on Earth). Consequently, desert areas easily radiate their heat energy out to space, and day and night temperature differences are considerable.

Elevation also influences seasonal patterns. Changes in elevation can affect the environment as much as changes in latitude. Average air temperature falls approximately 1˚ C for every 150 meter increase in elevation, and, in terms of growing season, every 300 m increase in elevation is roughly equivalent to moving poleward by 400-500 km (roughly four to five degrees of latitude). Mountain tops can be thought of as climatic islands where, in the Northern Hemisphere,

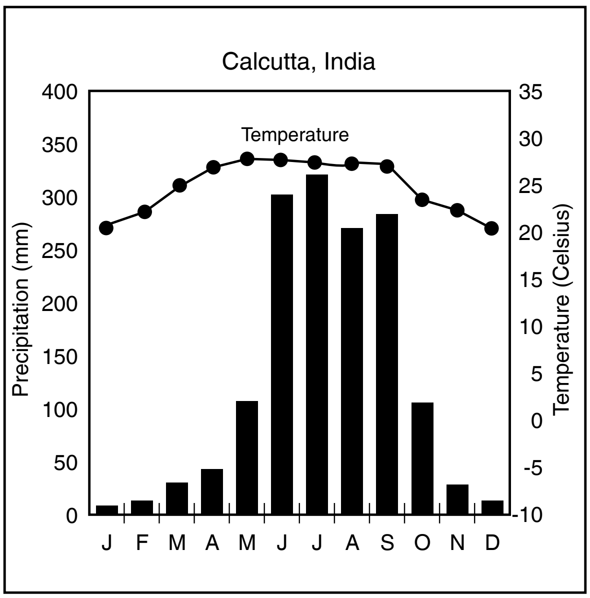
Figure EA-I-11: Impact of Elevation on Climate Zone



northern species extend their ranges southward on mountains where conditions resemble those of more northern latitudes. Plants growing on the top of New Hampshire's Mt. Washington (1,935 m) would feel right at home growing at sea level in the Arctic tundra, 2,400 km to the north in Canada. See Figure EA-I-11.

Students can study each of these effects by looking at GLOBE school data. A climatogram shows the monthly mean temperature and monthly total water equivalent of the precipitation for the whole year. Comparing these diagrams for schools in different areas (see Figure EA-I-12) makes these differences clear and prompts questions about the reasons for these differences.

Figure EA-I-12: Climatograms for Calcutta, India and Berkeley, California



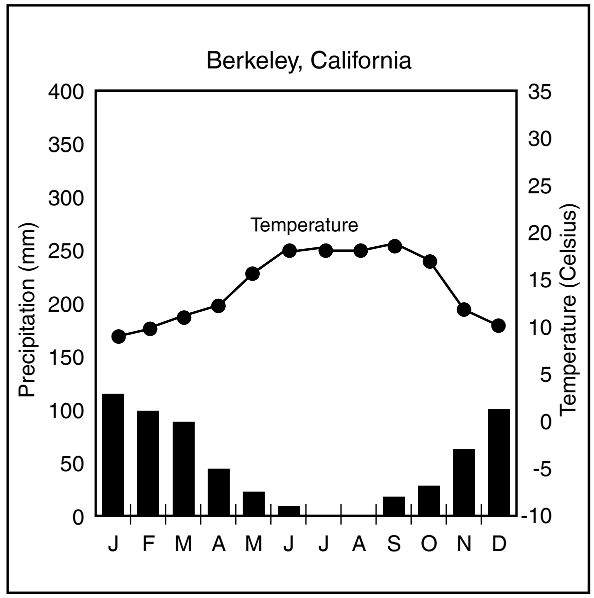
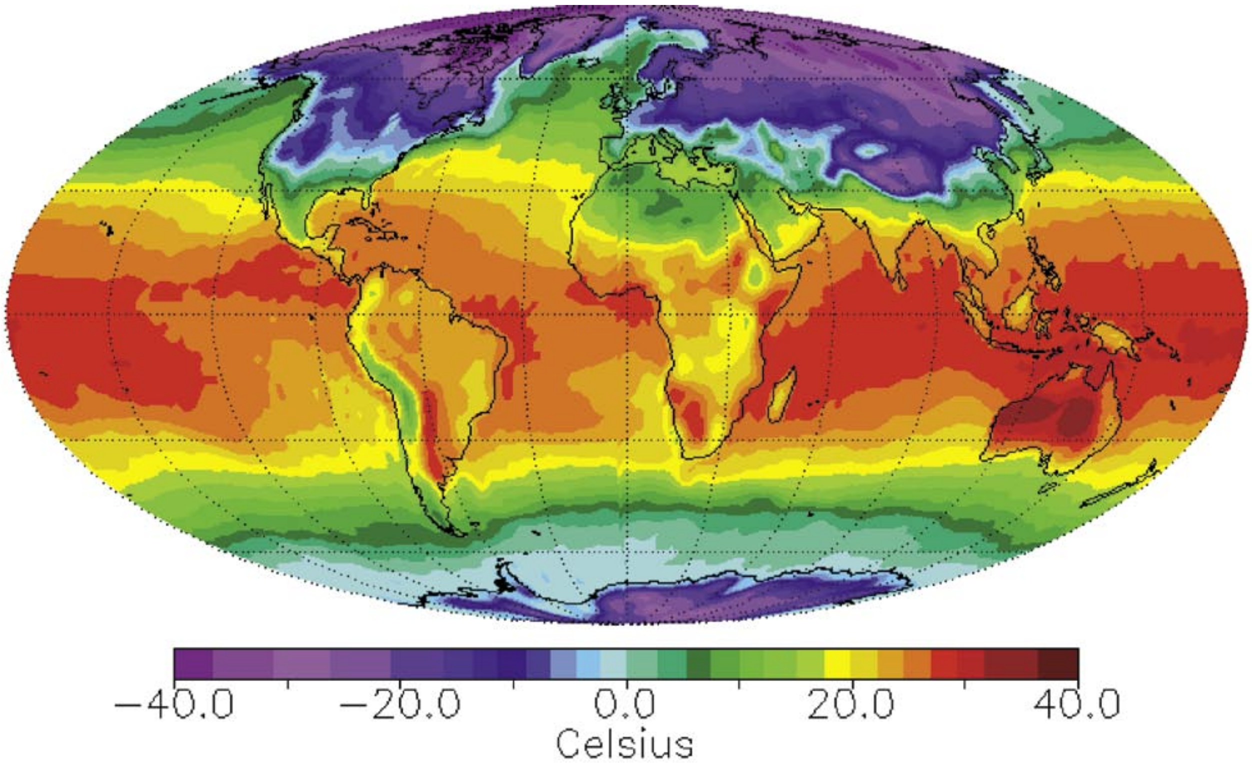
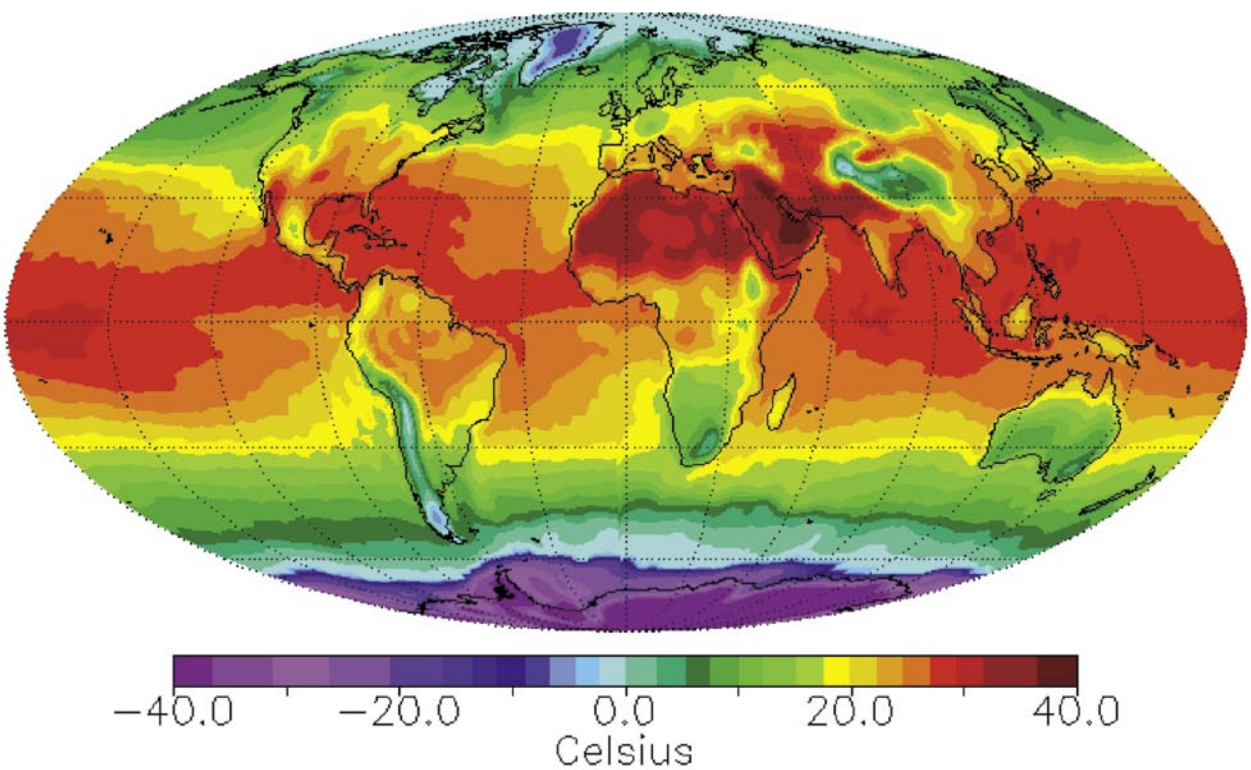


Figure EA-I-13: Global Surface Air Temperature in January and July, 1988.



January Air Temperature



July Air Temperature

The Earth System through the Seasonal Cycle

In GLOBE, the seasonal cycle plays a role in the timing of some measurements. Examining GLOBE data through the seasonal cycle can give you some understanding of how Earth works as a system. We can see this by examining some examples of how the seasonal cycle affects different components of the Earth system. The examples here may provide some background material to better understand and interpret GLOBE data. These examples indicate our current understanding and are based on previous studies. Many of the GLOBE data will reveal some of these seasonal patterns. As well, GLOBE data will expand and refine our understanding of seasonal patterns by examining many sites over a long period of time.

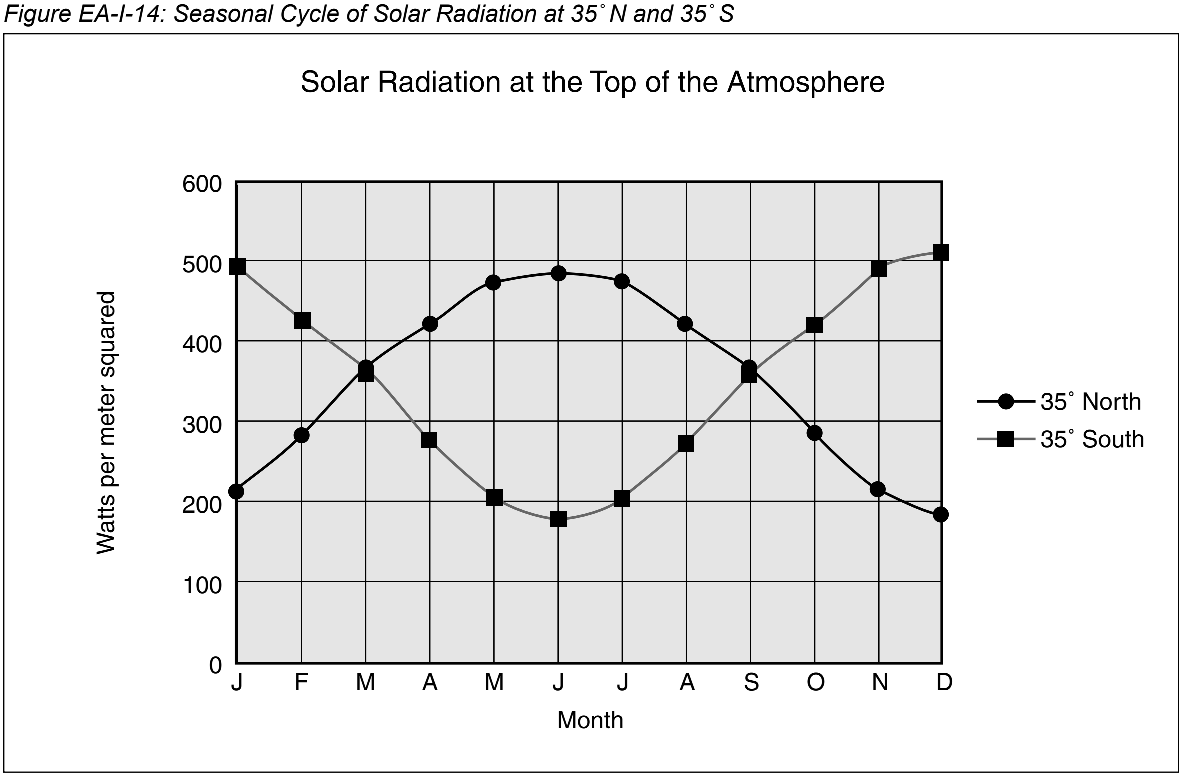
The Atmosphere through the Seasonal Cycle

Temperature

The relationship between air temperature and the number of daylight hours is a familiar seasonal change to people in mid and high latitudes. The air in the lowest layer of the atmosphere is warmed through its contact with Earth's surface. During the summer (July in the northern hemisphere and January in the southern hemisphere), when the elevation of the sun is high, the more concentrated input of energy from the sun and the increase in daylight hours warm the surface which in turn warms the air. During the winter (January in the northern hemisphere and July in the southern hemisphere), when the amount of solar radiation is spread over more surface area because the elevation of the sun is low and there are fewer daylight hours, the sun warms the surface less, resulting in less heating of the air. Compare the distribution of solar radiation in January and July (Figure EA-I-7) with the temperature distribution in January and July (Figure EA-I-13) respectively.

It takes time for Earth's surface to warm and for the atmosphere to fully respond to these changes in surface warmth. The time when the solar radiation is the strongest outside the tropics is in June in the northern hemisphere and December in the southern hemisphere. See Figure EA-I-14. This is when the solstices occur. However, generally tem-

Figure EA-I-14: Seasonal Cycle of Solar Radiation at 35˚ N and 35˚ S

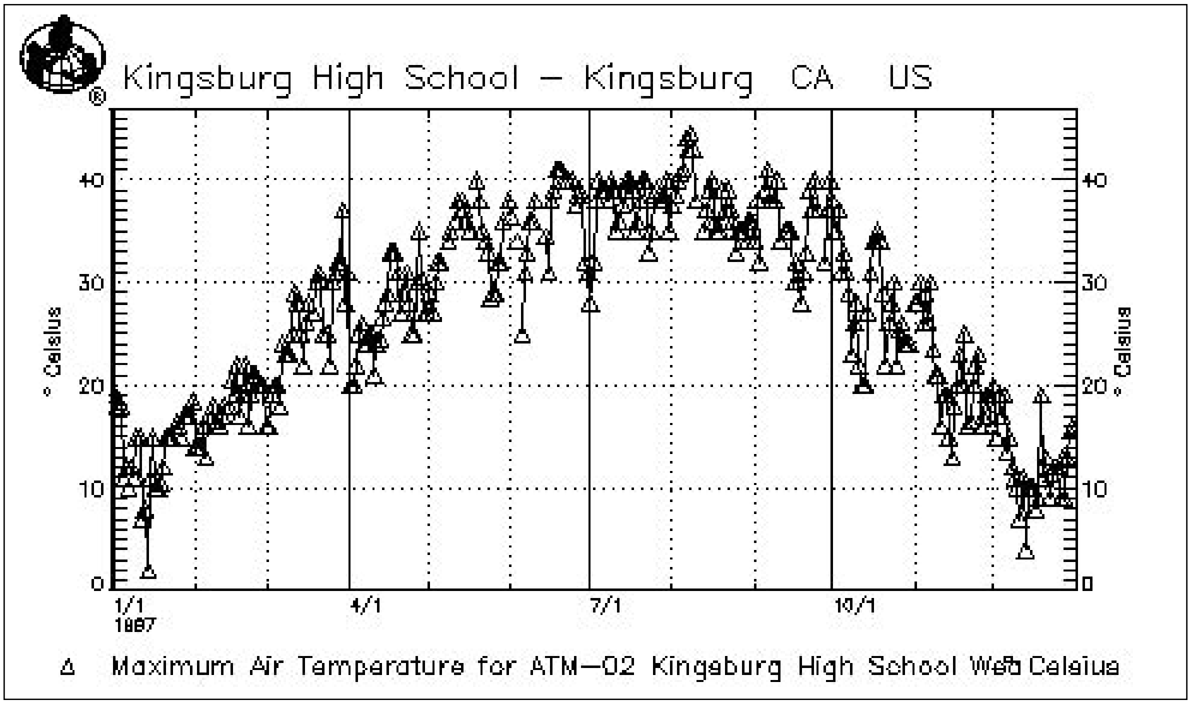


peratures are warmest about two months later, in August in the northern hemisphere and February in the southern hemisphere. See Figure EA-I-15. This is due to the amount of time required to heat the upper layer of the oceans and the lower layer of the atmosphere.

Precipitation

At low latitudes, seasonal temperature changes are not as dramatic as in middle and high latitudes, but there is usually a definite seasonal change in precipitation patterns. Equatorial regions often experience "wet" and "dry" seasons. The time of

Figure EA-I-15: Seasonal cycle of maximum surface air temperature at Kingsburg High School in the United States (located at about 35˚ N) and Shepparton High School in Australia (located at about 35˚ S)



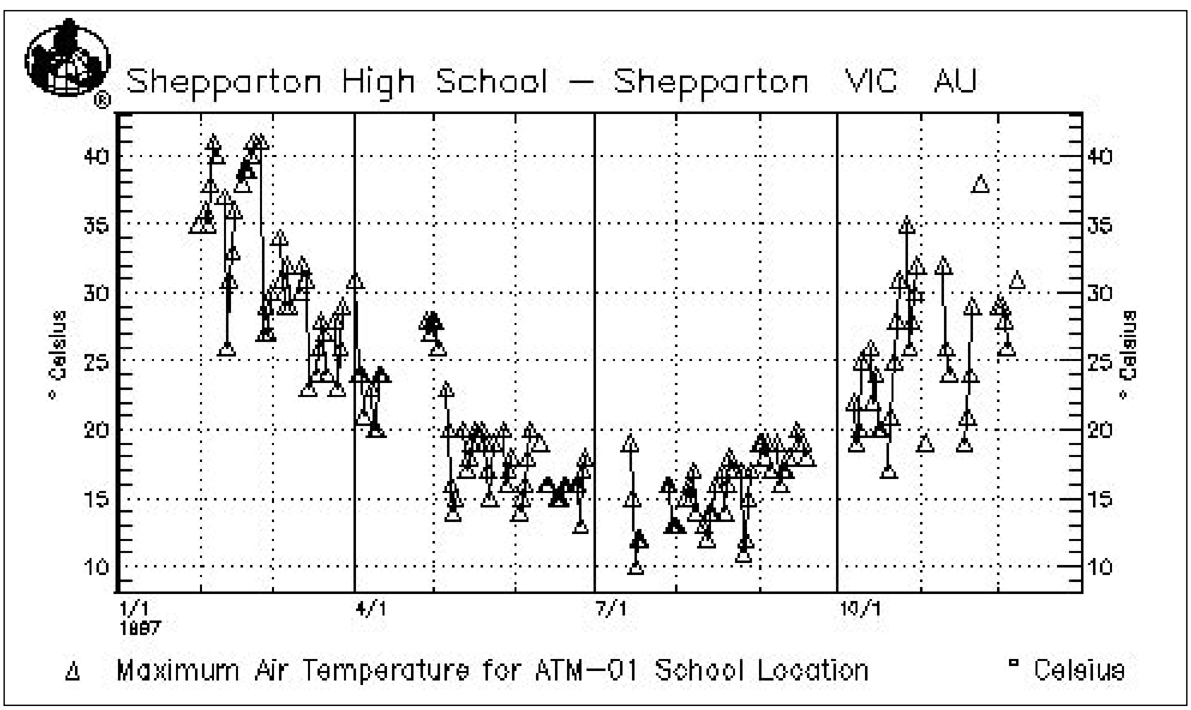
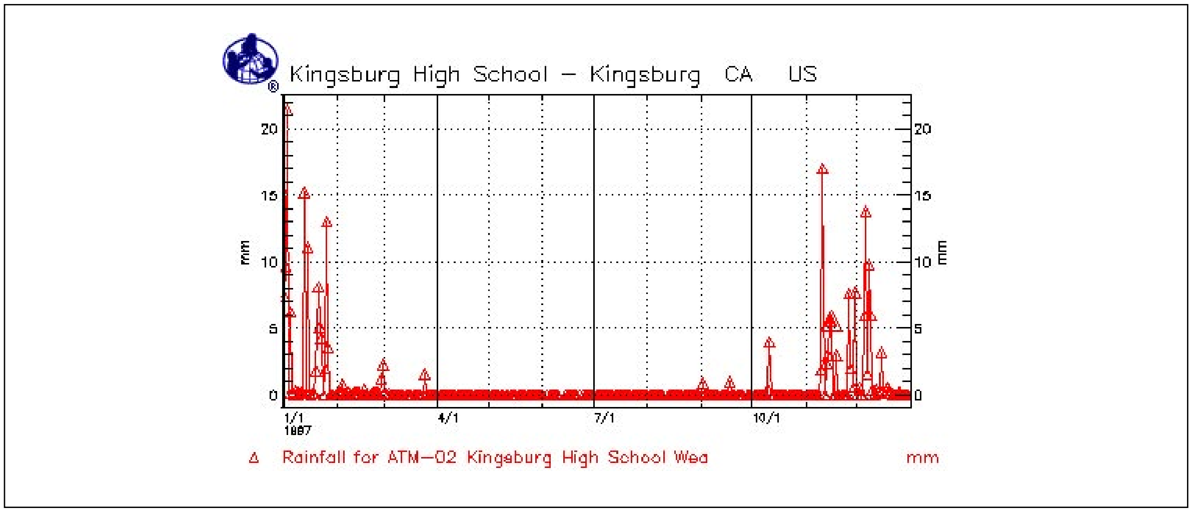
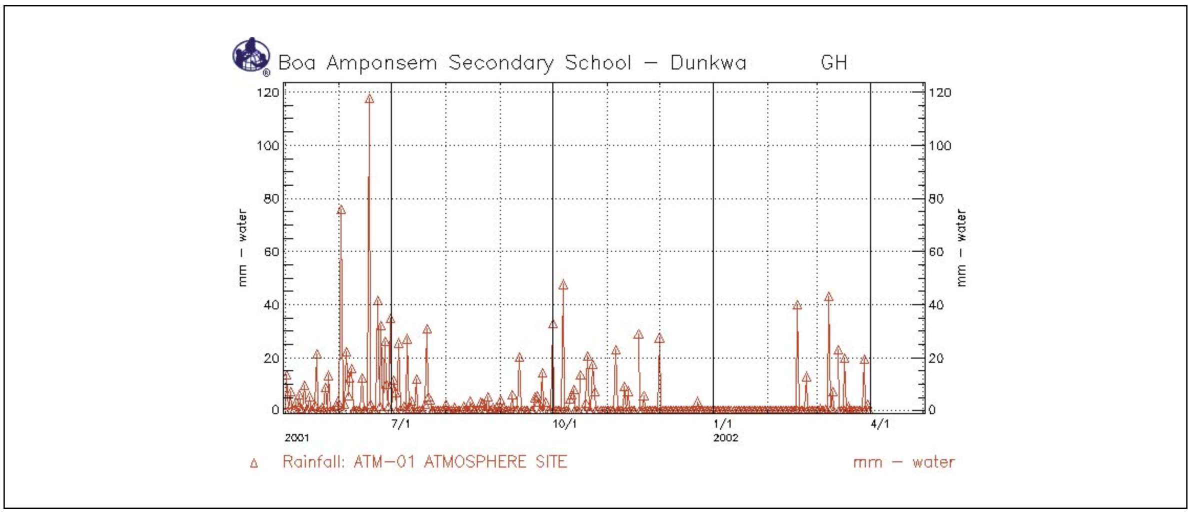
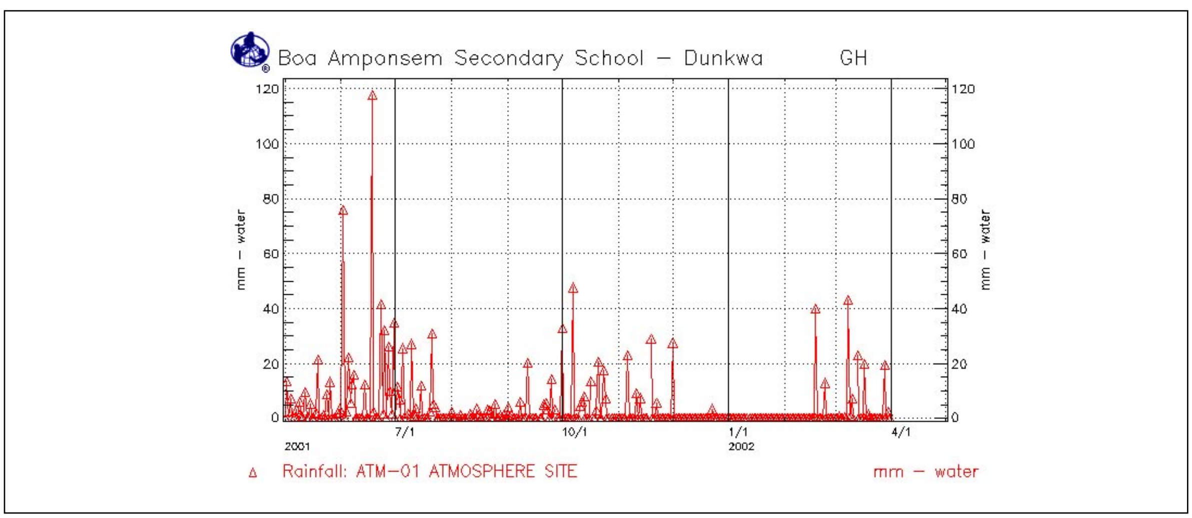


Figure EA-I-16: Seasonal cycle of precipitation through the year at Kingburg High School in California USA, Reynolds Jr. Sr. High School in Pennsylvania USA, and Boa Amponsem Secondary School, Dunkwa, Ghana







year at which these occur is dependent on many factors such as regional topography and proximity to large bodies of water.

Other localities show seasonal patterns in precipitation as well. See Figure EA-I-16. Some regions receive no precipitation for months at a time. In other locations precipitation is evenly distributed throughout the year. Some places have one rainy season and one dry season, while others have two of each during the year. The timing of rains within the year has a major effect on agriculture. Mediterranean climates are characterized by winter rains while other regions experience only summer rains.

Water Vapor and Relative Humidity

Since the saturation value for atmospheric water vapor is strongly influenced by temperature, both the absolute concentration of water vapor and the dew point temperature have a strong seasonal cycle. The highest concentrations of water vapor and the highest dew points occur during summer and the lowest in winter. Relative humidity tends to be highest during the rainy season. However, it can be high even in the winter when the air is relatively cold.

Clouds

In the tropics, a band of low pressure and cloudiness known as the Intertropical Convergence Zone (ITCZ) extends across the oceans. Global satellite imagery shows clouds that extend across oceanic regions, where thunderstorms are active. The average position of the ITCZ varies with the season, moving north in northern hemisphere summer and south in southern hemisphere summer. See Figure EA-I-17.

There are seasonal variations in clouds in other regions. Generally, there is greater cloud cover during the rainy season when observed cloud types are mostly nimbostratus and cumulonimbus. During warmer months, cumulus type clouds are most likely to be observed in most locations due to the heating of Earth's surface. During winter months, because there is less heating, stratus type clouds are more often observed. Vigorous frontal systems that occur during the spring and summer months at mid latitudes can, and often do, cause large thunderstorm clouds (cumulonimbus). Near the eastern coastlines, cooler water can bring stratus type clouds to the region year-round.

Aerosols

Aerosols are colloids consisting of liquid droplets or solid particles dispersed throughout a gas. Fog and mist are examples of liquids dispersed in a gas and smoke is an example of solid particles dispersed in a gas. Aerosols affect the optical thickness of the atmosphere being greatest during summer and least in winter. Other seasonal events can also influence the amount of haze, especially dust storms, forest fires and agricultural activities.

Atmospheric Composition

Atmospheric trace gas concentrations also exhibit distinct seasonal cycles. The longest record of a trace gas measurement is for carbon dioxide (CO_2) and its seasonal cycle reflects the seasonality of forest growth. Lowest concentrations occur in the northern hemisphere spring and summer as the biosphere uses CO_2 for photosynthesis. Concentrations increase during northern hemisphere autumn and winter as CO_2 is no longer taken up by vegetation growth, and decay of leaves puts CO_2 back into the atmosphere. This cycle is dominated by the larger extent of terrestrial vegetation in the northern hemisphere. See Figure EA-I-18.

Another important trace gas is ozone, which exists in the lower atmosphere as both a natural component, where its primary source is the stratosphere, and as a pollutant, where it is formed as a result of emissions from combustion sources. At northern middle latitudes, surface ozone peaks in the summer when sunlight is most intense and photochemical reactions happen most quickly, converting hydrocarbons and nitrogen oxides into ozone. At southern mid-latitudes, on the other hand, summer concentrations of surface ozone are lower because there are less emissions from combustion than in the Northern Hemisphere. In the tropics, surface ozone concentrations are generally highest in September and October because this is the time when widespread biomass burning occurs and gases from these fires generate ozone through photochemistry. Thus, the seasonal cycle of surface ozone concentrations is affected by human activity and is quite variable depending on where observations are made.

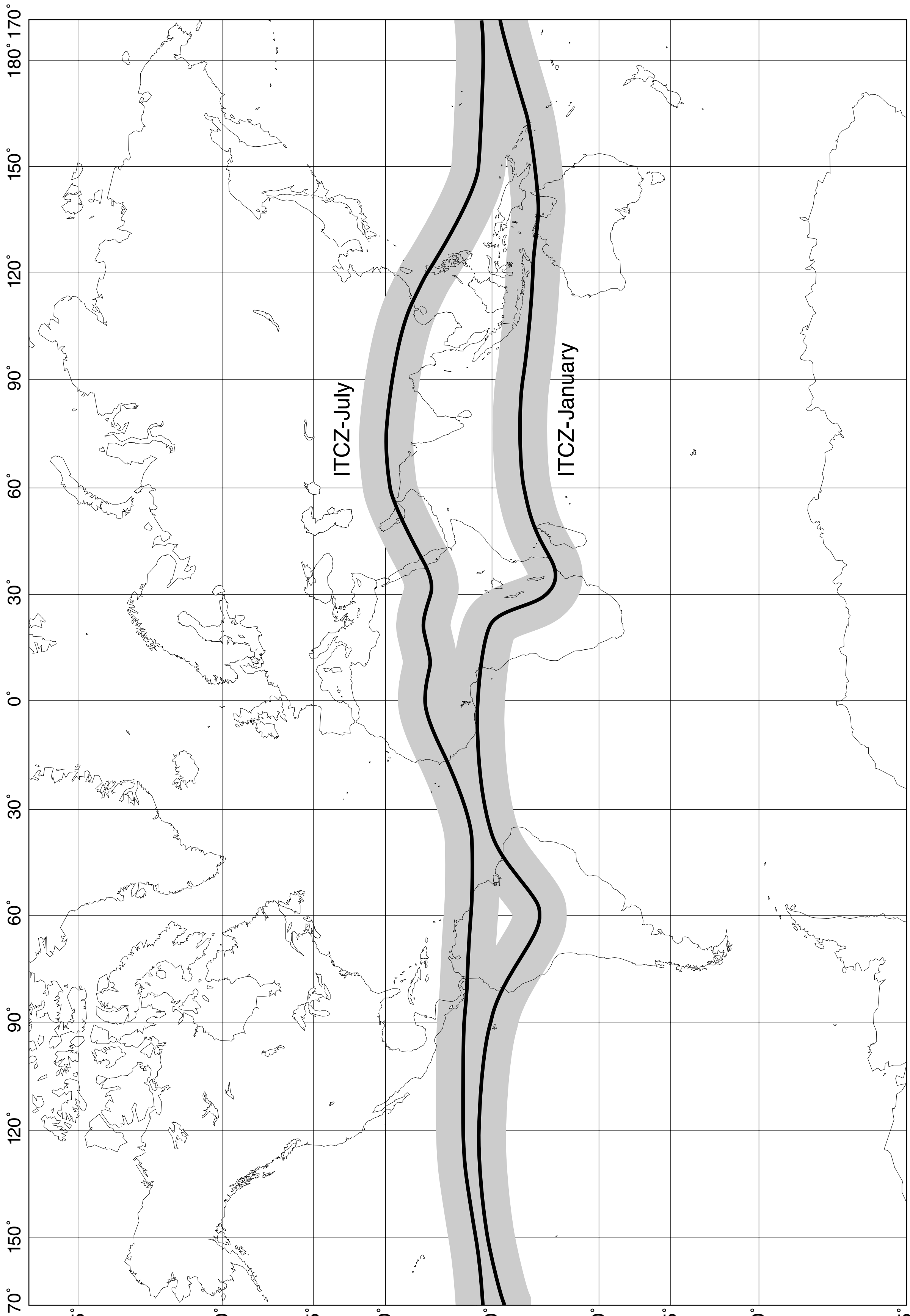


Figure EA-I-17: Average Positions of the Intertropical Convergence Zone (ITCZ) in January and July

Figure EA-I-18: The seasonal variation of carbon dioxide (CO_2) in the atmosphere from 1986 through 1988 measured at Mauna Loa Hawaii

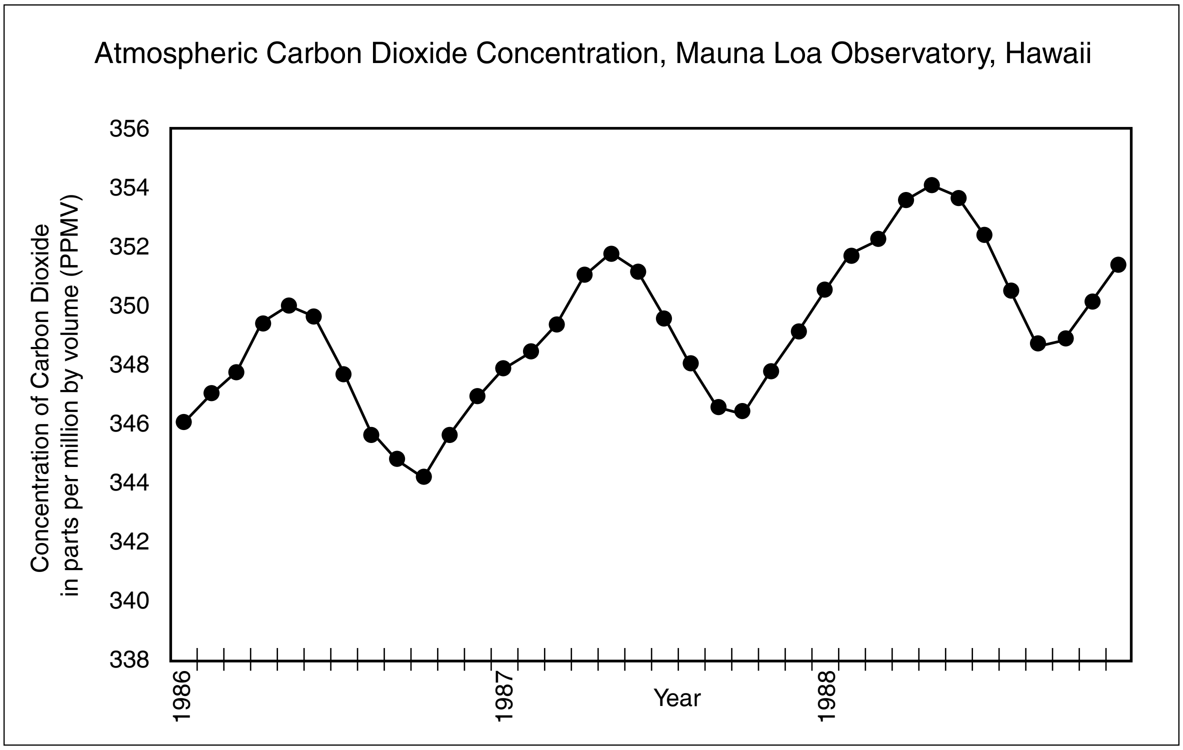
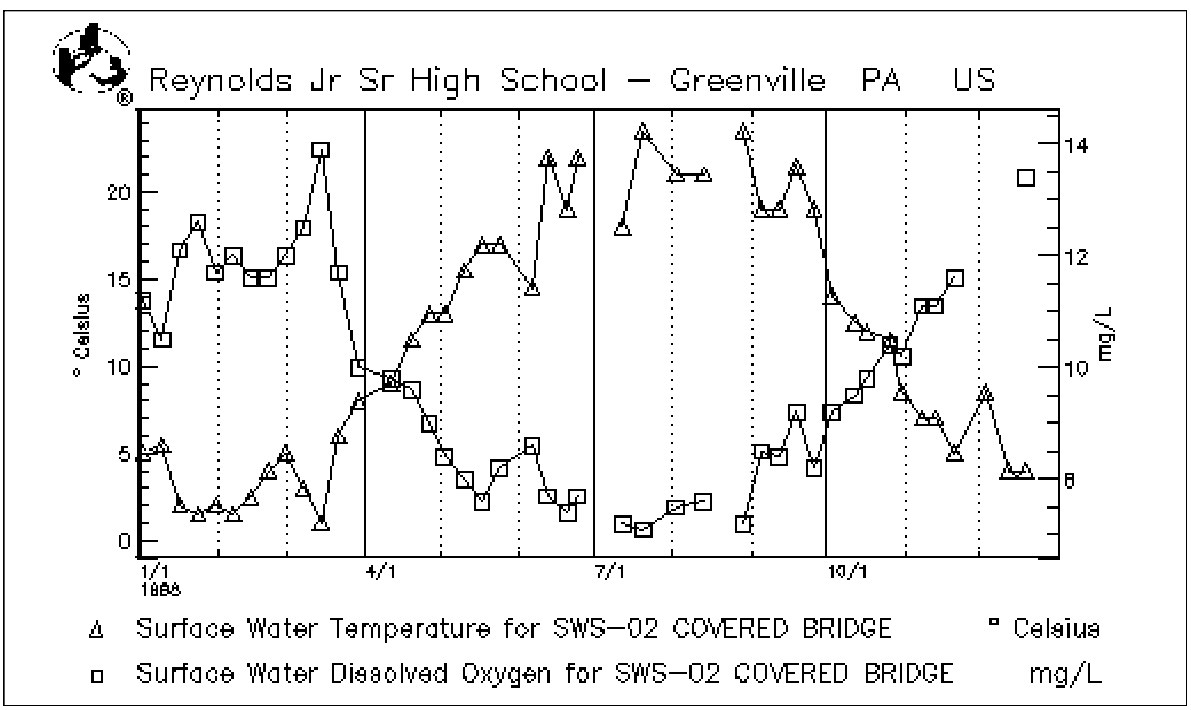


Figure EA-I-19: Surface water temperature and dissolved O_2 at Reynolds Jr. Sr. High School in 1998



Surface Water through the Seasonal Cycle

The physical and chemical characteristics of a body of water are influenced by the seasonal cycle through changes in solar radiation, precipitation, air temperature, wind patterns and snow and ice melting. Figure EA-I-19 shows how temperature and dissolved oxygen (DO) varies throughout the year. The saturation level of DO is inversely related to temperature (i.e. as temperature increases the amount of DO that can be dissolved in water decreases). The observed pattern in any given water body depends on the amount of biological activity.

Seasonal Turnover in Lakes

Many lakes show seasonal patterns of vertical mixing. Lakes in either warm temperate or cold temperate zones show one mixing event (or turnover) in the year. In other temperate regions that bridge temperatures of cold and warm temperate zones or at high elevations in subtropical regions, there are two turnovers. The spring turnover occurs after ice melts. Ice floats because it is less dense than water, which is most dense at 4˚C. As water warms to near 4˚C, the surface water may become more dense than bottom water and sink. Relatively little wind energy is required to mix the whole lake (spring turnover). As spring progresses, the top layers of the lake become warmer and thus less dense. The colder, more dense water remains on the bottom, and a zone of rapid temperature change occurs between the warmer layer on the top and the colder layer on the bottom. This is known as *thermal stratification.* In the fall, with less solar radiation reaching the water and greater heat loss from the surface at night, the temperature stratification breaks down. Eventually the mixed layer extends downward, until the temperature and density differences between the mixed and bottom water become so slight that a strong wind in autumn can overcome any resistance to mixing and the lake undergoes a turnover.

Plant Growth in Lakes, Estuaries, and Oceans

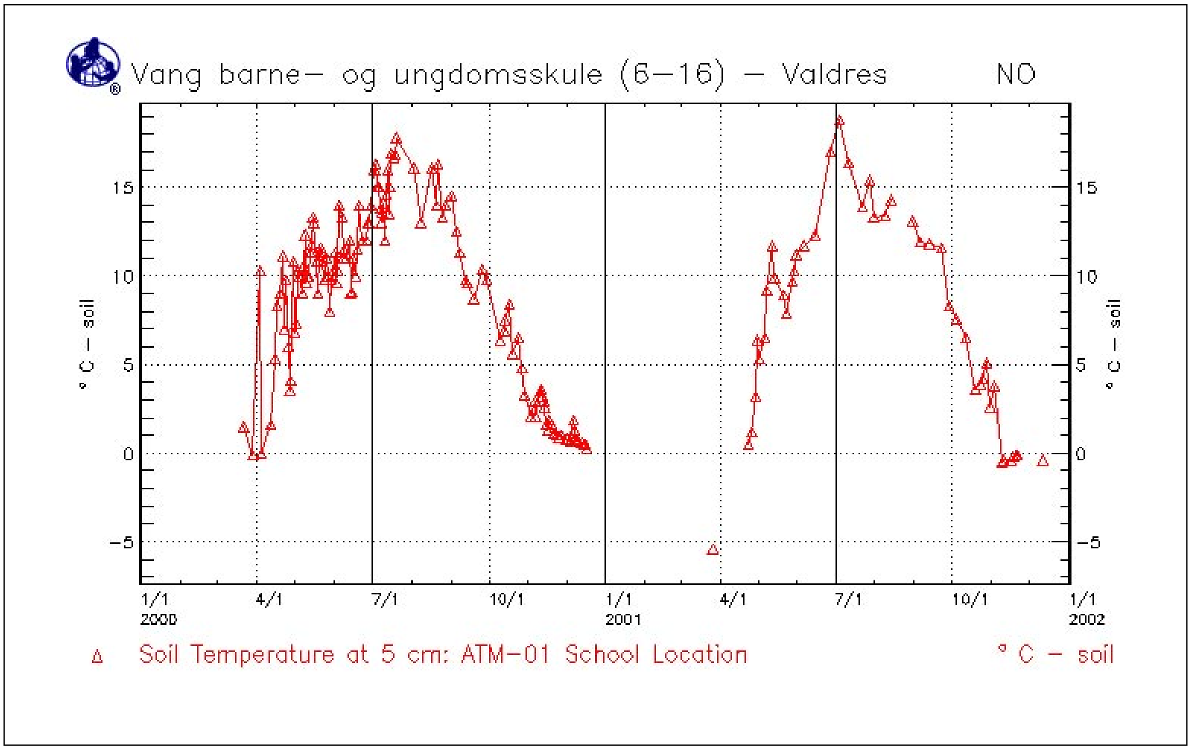
Seasonal changes in water temperature, sunlight, and nutrient availability affect plant life in water bodies. Nutrients tend to fall through the water column, and vertical mixing usually returns nutrients to near the surface and may promote rapid growth in phytoplankton. Increases in plant growth trigger changes in the entire food chain and can result in increased animal growth and reproduction, as well as increased bacterial decomposition. In temperate areas, increases in water temperature and sunlight availability in the spring combine with seasonal increases in nutrients mixed up from deeper water to promote rapid growth. In tropical areas, where sunlight amount and temperature change little throughout the year, changes in wind patterns can result in vertical mixing in oceans, seas and large lakes.

Most of the plant production takes place in surface and near surface waters where light is available for photosynthesis. During the summer months there is little vertical mixing in some lakes and estuaries. Organic matter falls from the surface to deeper waters and is eaten by animals or decomposed by bacteria. These organisms require oxygen. Respiration, lack of vertical mixing and warm temperatures can lead to low oxygen levels. In some places the summer can become a critical period for fish and other creatures that live in bottom waters.

Streams and Rivers

Streams and rivers can show seasonal changes in the amount and composition of water resulting from changes in precipitation, evaporation, snowmelt, and run-off. How these factors affect the biota are areas of active research. Soluble chemicals which have accumulated in the winter snow pack tend to be concentrated in the first melt water and can cause rapid changes (usually decreases) in the pH of streams. The first big rain storm following a prolonged dry period also washes chemicals that have accumulated on roads and other land surfaces into water bodies. The volume of water flowing in a stream or river often affects its water quality. Low flow conditions can permit the buildup of nitrates or the depletion of dissolved oxygen. Floods and major rain storms wash large amounts of debris into waterways and can reshape the entire flood plain of a river or stream while transporting soil particles to new locations.

Figure EA-I-20: Seasonal cycle of the 5 cm soil temperature at Vang barne-og ungdomsskule in Valdres, Norway from January 1, 2000 to January 1, 2002.



Soil through the Seasonal Cycle

Soil Temperature

As with the atmosphere and water bodies, the most obvious seasonal change in soils is in their temperature. As the sun gets higher in the sky in the spring the increase in solar radiation warms the surface, increasing the soil temperature.

The soil undergoes a strong daily (diurnal) as well as seasonal cycle in temperature, especially at mid latitudes. See Figure EA-I-20. The soil cycle lags slightly behind the air temperature cycle so that, in general, the soil temperature is slightly warmer than air at night, and is slightly cooler than air in the morning. The lag time will depend on the particle size distribution, the amount of organic matter, and the amount of moisture in the soil. The cycle is most evident at the surface of the soil and decreases with depth. Soil scientists use the temperature at 50 cm to define the Mean Annual Soil Temperature (MAST) which stays relatively constant from year to year. This temperature cycle in soils is important in that it has a strong effect on phenology, influencing when plants will "green up" in the spring, or "die back" in the fall. It also affects the insulation needed for pipes that are buried in the soil to prevent freezing in the winter, and is used to control temperatures in basements and storage areas which are below ground.

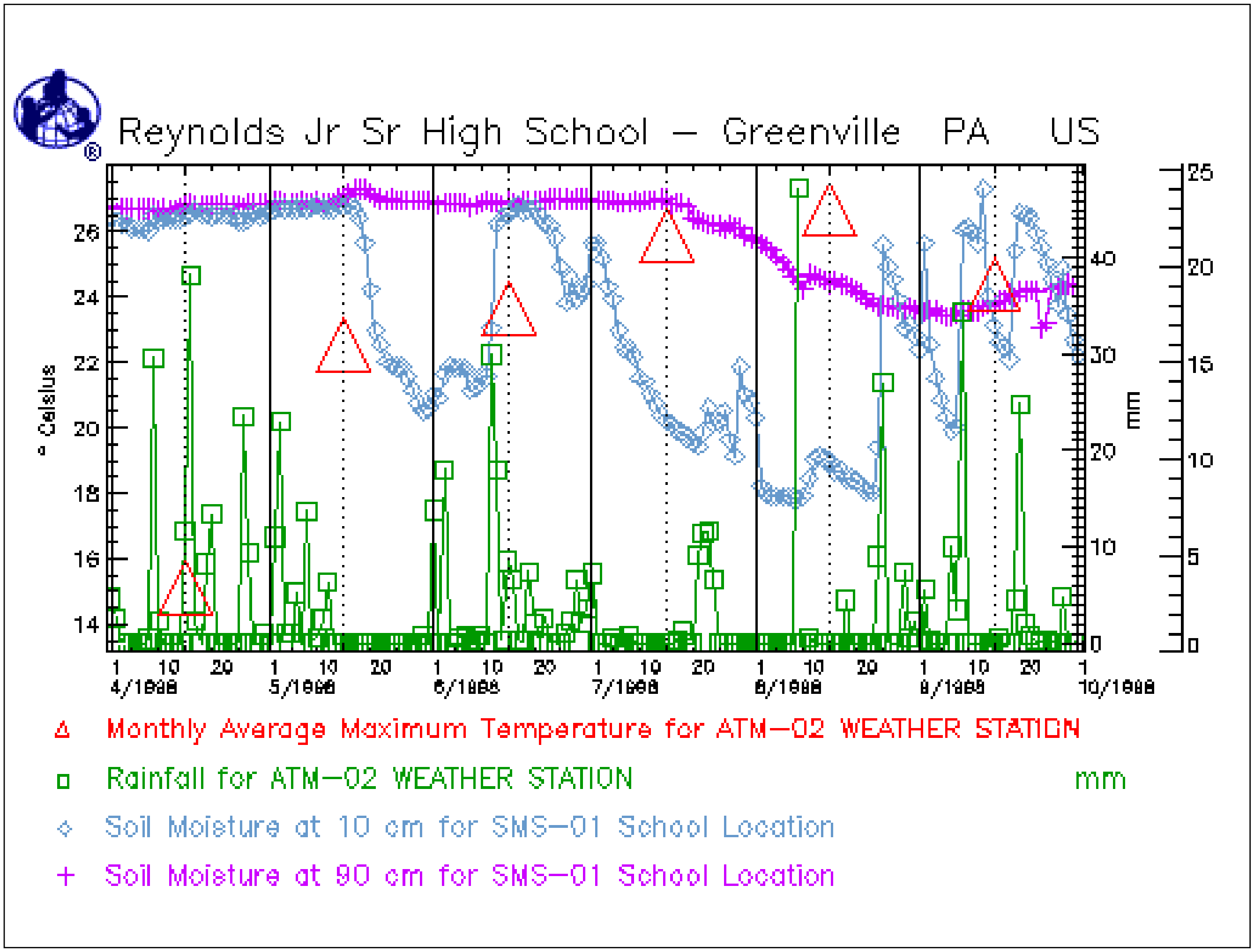
Soil Moisture

Another characteristic of soil that changes through the seasonal cycle is the soil moisture. The main source of soil moisture is precipitation. The seasonal variation in soil moisture is controlled by seasonal variations in precipitation and snow melt and by the effect of seasonal variations in temperature on evaporation. See Figure EA-I-21. For example, if the rainy season occurs during the winter, the soil water content will be high, while the summer will be a time of increasing temperature leading to higher evaporation and dryer conditions in the soil.

Decomposition

The decomposition of organic material is also affected by seasonal changes. The microorganisms that perform the decomposition process require moisture and heat in order to thrive. Thus, the rate

Figure EA-I-21: Maximum air temperature, precipitation, and soil moisture at 10 and 90 cm at Reynolds Jr. Sr. High School in Pennsylvania USA from April 1, 1998 to October 1, 1998.



of decomposition of organic material is dependent on the soil temperature and moisture. All of these vary through the seasonal cycle, and so there is a seasonal cycle in the rate of decomposition of organic material. This seasonal cycle may not be as simple as that exhibited by temperature and moisture. This is because the soil microorganisms may die or become inactive when conditions are too hot, too cold, too dry, or completely saturated. In general, the more decomposition, the more CO_2 and N_2O are produced and exchanged into the atmosphere.

Land Cover and Phenology through the Seasonal Cycle

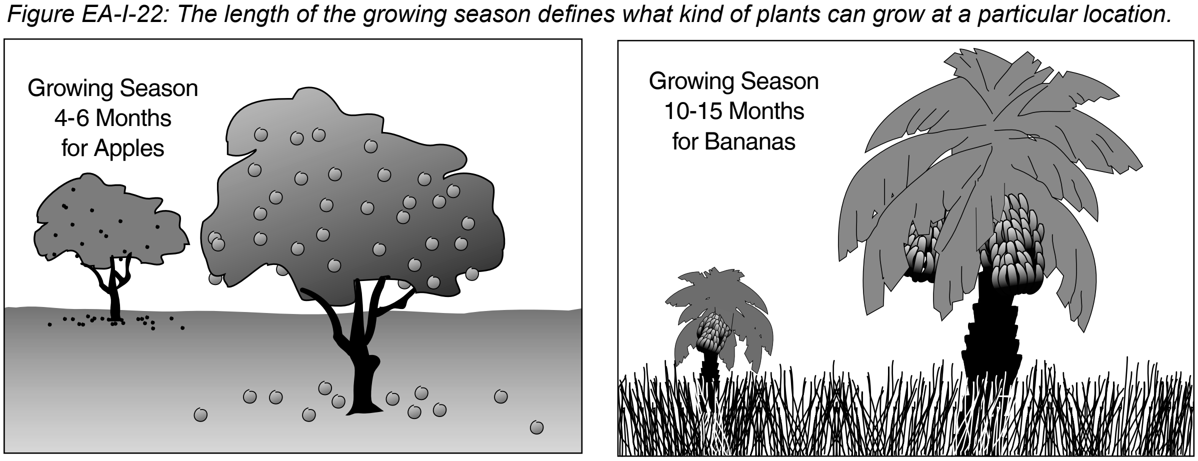
Phenology is the study of living organisms' response to seasonal and climatic changes in the environment in which they live. The GLOBE measurements in the Phenology protocols (this chapter) focus on plant phenology. Seasonal changes include variations in day length or duration of sunlight, precipitation, temperature, and other life-controlling factors. The plant growing season is the period between green-up and green-down (*senescence*). See Figure EA-I-22. Green-up and senescence can be used to examine regional and global vegetation patterns, interannual variation, and vegetation responses to climate change. A change in the period between green-up and senescence may be an indication of global climate change.

Plant green-up is initiated when *dormancy* (a state of suspended growth and metabolism) is broken by environmental conditions such as longer hours of sunlight and higher temperatures in temperate regions, or rains and cooler temperatures in desert areas. As plants begin green-up, leaf chlorophyll absorbs sunlight for photosynthesis. Photosynthesis fixes carbon dioxide from the atmosphere.

With the start of green-up, plants also begin to transpire water from the soil to the atmosphere. This affects atmospheric temperature, humidity, and soil moisture. During green-down, through leaf fall, plants reduce water loss when water supply is greatly limited during winters for temperate plants, and during dry spells for desert plants.

Monitoring the length of the growing season is important for society because the length of the growing season has a direct effect on food and fiber production and thus on society's ability to support itself. Therefore, in investigating this seasonal variation, GLOBE schools are providing information to scientists so that they can better understand the Earth system and how it responds to various influences and to society so that it can be better prepared to adapt to variations in the length of the growing season.

Figure EA-I-22: The length of the growing season defines what kind of plants can grow at a particular location.



The Earth System on Different Spatial Scales

The Earth as a System at the Local Scale

Components

Each of the GLOBE investigations requires students to choose a study site or a set of sample sites where they will take their measurements. At each of these sites many of the components of the Earth system investigated by GLOBE students are present. At the hydrology study site, for example, air, soil and a body of water are all present. Terrestrial vegetation is often present as well, and for a number of sites, snow or ice – elements of the cryosphere – are present at least some of the year. Figure EA-I-23 is a photograph of the hydrology study site at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA where students can identify each of these components and can examine where interactions between the components take place.

Some examples of these interactions are:

- Evaporation and exchange of heat between air and water.
- Exchanges of water and gases between the air and vegetation.
- Exchanges of water and nutrients between soil and the root systems of grasses and trees.
- Evaporation and exchange of heat and gases between air and soil.
- Exchanges of water, chemicals, and sediments between soil and water at the sides and bottom of a water body.
- All of the Earth system components are exposed to the sunlight. This exposure to sunlight affects the temperatures of the various components, the photosynthesis in plants, rates of decomposition in soils, and chemical cycles.

Cycles: Energy, Hydrologic, and Biogeochemical

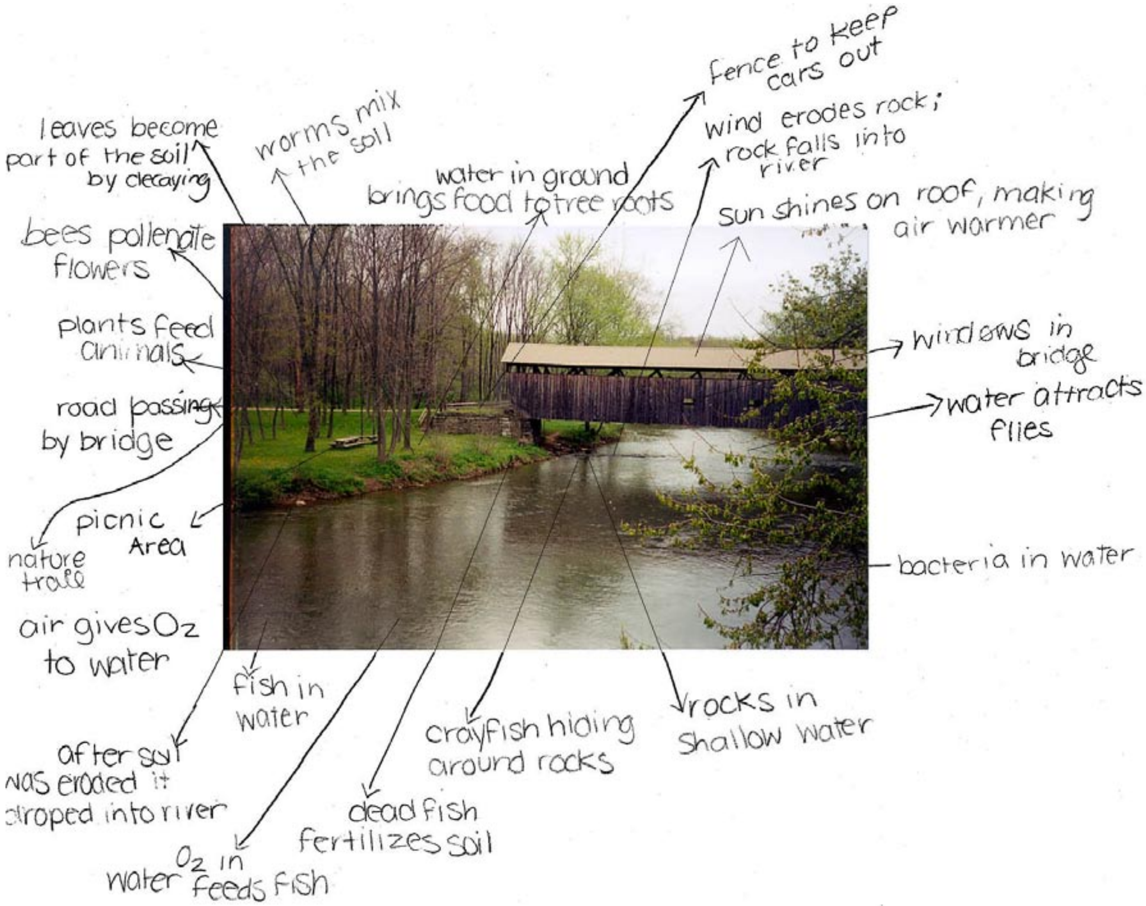
The exchanges among the air, water, soil, and terrestrial vegetation are parts of the energy cycle, the hydrologic cycle, and the various biogeochemical cycles. As an example, let's consider how energy and water are cycling through this site (Reynolds Jr. Sr. High School) and discuss pH, which influences the biogeochemical cycles.

Sunlight strikes the surface of the river as well as the trees, grass, and pavement on the bank. Some of the energy in the sunlight heats the water and the land surface, raising the temperature of the surface soil and water. The remaining energy is reflected back up into the atmosphere. Depending on the cloud cover, some of this energy may be reflected again toward the surface. Water from the river and the soil evaporates, cooling the surface and taking energy into the atmosphere. When the temperature of the air is lower than that of the surface, the air is warmed through contact with the land and water. When the reverse is true, the land and water are warmed through contact with the air. As the soil warms, energy is stored in it. As the river flows, it carries away any energy stored through the warming of the water. Similarly, the air brings energy with it or carries energy away. Precipitation may be warmer or colder than the surface, and the exchange of energy between the rain or snow and the surface will also provide heating or cooling.

GLOBE measurements allow you to track some of the flow and storage of energy. The key measurements are those of the air, surface water, and soil temperatures. With these you can calculate the direct energy exchange between the atmosphere and the surface. Temperature, soil moisture, and relative humidity measurements enable the calculation of evaporation rates from the land and water surfaces. You can compare the amount of energy lost from the surface through evaporation to the direct heat exchange with the atmosphere and determine at what times one is more significant than the other.

In the hydrologic cycle, water is exchanged among the air, river, soil, and land vegetation.

Figure EA-I-23: Photograph of the hydrology study site at Reynolds Jr. Sr. High School in Greenville Pennsylvania USA annotated with various interactions between components of the Earth system



Precipitation forms in the atmosphere and then falls onto the surface – the water, soil, plants, and pavement. Water flows off the pavement and into the soil. Some flows across the surface or through the soil into the river. The various grasses and trees take in water through their roots and lose this water to the atmosphere through their leaves. Some water evaporates from the soil and from the surface of the river. If the surface is colder than the dew point of the air, moisture in the atmosphere will directly condense on the surface. Water also flows into the site from upstream and up hill and flows downstream, out of the site, in the river.

GLOBE measurements of precipitation capture most of the inputs of water from the atmosphere. The flow of water in the river can be calculated if you know the slope of the river bed, the depth profile across the river, and the level of the water. Some hydrology study sites are located on rivers where flow is monitored by government agencies, and these discharge data can be obtained from public databases. Storage of water in the soil can be calculated by measuring soil porosity and soil moisture. Evaporation rates can be calculated by measuring relative humidity and air and surface temperatures. You can see how the soil moisture responds to precipitation and to dry periods as well. You can study whether the river level is influenced by local inputs or primarily controlled by what happens upstream.

The chemical composition of the precipitation can alter the composition of the river water and of the soil, and affect plant and animal life. It can also impact the rate of decomposition of organic material in the soil and of rocks and minerals in the river bed. The pH of precipitation is determined by the gases and particles which dissolve in rain drops and snow flakes. Carbon dioxide in the air tends to give precipitation a pH of about

5.6, while other constituents move this figure up or down. Most combustion-related gases lower pH, while alkaline airborne soil particles raise pH. Chemistry is happening in the soil and the river water as well. If the alkalinity of either is high, the pH will not respond significantly to the different pH of precipitation, but if it is low, the pH will change. Over time, the pH of the soil may change due to the cumulative effects of precipitation. Ultimately the pH of the river reflects the pH of the surrounding soil, of precipitation, and of the water upstream.

GLOBE measurements of the pH of the precipitation, soil horizons, and surface water, and the alkalinity of the surface water enable you to examine the question of how the river pH responds to precipitation events and floods. Over time, a school's dataset may show changes in soil pH. pH variations through the soil profile may also illustrate how pH is changing.

Biogeochemical cycles also promote exchanges between the different components of the Earth system. Examples of these exchanges include:

Exchanges between air and water:

- transfer of oxygen, carbon dioxide, nitrogen, water vapor (through evaporation) and other gases

Exchanges between water and soil:

- storage of water in the soil
- percolation of water through soil into the water bodies or ground water carrying chemicals and particles
- runoff processes.

Exchanges between the soil and land cover:

- use of water stored in soil by the roots of the land cover
- use of nutrients stored in soil
- substrate for plants
- heat storage for plants and microorganisms
- air spaces for exchange of oxygen and carbon dioxide during respiration and photosynthesis

Exchanges between air and land cover:

- evapotranspiration process.

Exchanges between air and soil:

- precipitation and evaporation processes
- heat and energy transfer
- exchanges of gases produced in the process of decomposition of organic material and microbial respiration.

The rates of the exchanges of chemicals between the different components of the Earth system depend on a number of factors. These factors include the type of chemical reactions occurring within the different components, the temperature of the components, the concentrations of the various gases in each of the components and the motion of the components at the interface which promotes exchange.

Earth as a System at the Regional Scale

The processes that allow the components of the Earth system to interact on a local scale, such as a hydrology study site, may also act at the regional scale. See Figure EA-I-24.

What Defines a Region?

The regional scale is larger than the local scale and is generally characterized by some common feature or features that differentiate it from neighboring regions. Regions can be defined in different ways. They can have natural boundaries, human-made boundaries, or political/social boundaries. Some examples of regions are:

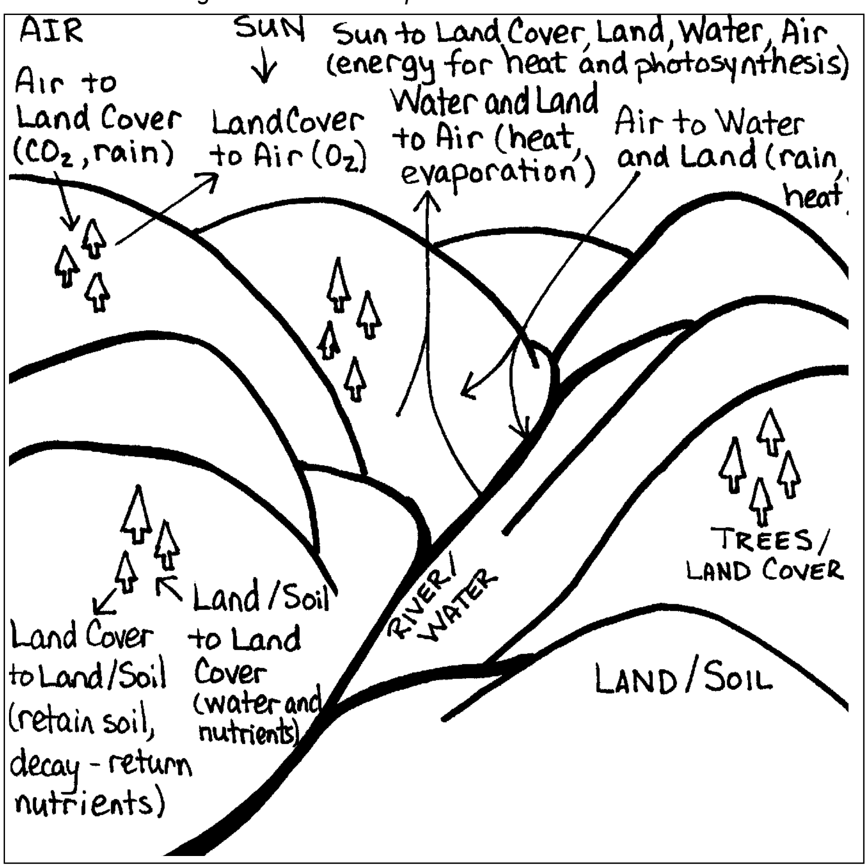
Natural
- a watershed
- a mountain range
- a river basin
- a desert
- a plain
- a peninsula

Human-made boundaries
- a watershed in which a boundary is a dam
- an area larger than a local study site bounded by highways, railroads, and bridges
- a natural area surrounded by populated regions or a populated region surrounded by a natural area
- a park or game preserve

Political/social boundaries
- a state or province
- a country

Many of the processes that cause the interactions between the different components of the Earth system at the regional scale are the same as those at the local scale. However, to quantify the magnitude of the processes, measurements generally must be taken at numerous locations throughout the region. For example, if one wants to study the urban heat island effect, temperature measure-

Figure EA-I-24: Diagram of Earth System at the Regional Scale Indicating Interactions Among the Different Components



ments are required within the urban area as well as in the surrounding countryside. Furthermore, temperatures will differ between areas with lawns, plants, and trees, and those which are almost completely covered by buildings and pavement; what is observed in an area that is primarily residential may differ from that in a commercial or industrial area. So in order to get a better representation of the entire urban area, measurements from multiple sites are needed from different sections within the urban environment.

Likewise, suppose you want to develop a hydrologic model for a watershed of a river that flows into an estuary along the coast and the only GLOBE schools in the watershed are near the mouth of the river (where it enters the estuary). Using only these data for the entire watershed may lead to inaccuracies because temperature, precipitation, soil types and textures, and land cover, among other things, may differ greatly throughout the watershed. Measurements must cover more of the watershed to give an accurate model. The lack of spatial coverage for many data is a problem scientists frequently face. Sometimes a gross approximation is the best that a scientist can do with limited data. Hence, the more GLOBE schools taking data, the better!

Inputs and Outputs

In order to understand the Earth system at the regional scale you must consider the inputs and outputs to the region, in addition to the interactions among the components within the region. See Figure EA-I-25 The region may be somewhat closed in the sense that liquid water may not leave it, or it may be open with rivers flowing through it. The atmosphere will always be bringing inputs from outside and carrying outputs away; these include energy, water vapor, trace chemicals, and aerosols. The moving air also brings weather systems into and out of your region, which will affect air temperature, cloud cover, and precipitation.

Atmospheric inputs and outputs can greatly affect a region. The air entering your region will bring with it characteristics from upwind. These characteristics can include smoke from an industrial plant or agricultural burning, seeds from a forest or grassland, or moisture evaporated from lakes or rivers. The impact of these characteristics on your region must be considered. Likewise, what leaves your region in the atmosphere will influence other regions. As the atmosphere moves it carries trace gases from a region where they are produced to places where there are no local sources of these chemicals. The worst examples of air pollution happen where air is trapped, usually by mountains or by an *inversion layer* (a layer of air in which the temperature increases as you move from bottom to top) in the atmosphere. The winds also can carry away significant amounts of moisture and dust from a region. Plumes of Saharan dust are so prominent at times that they can be seen on satellite cloud images and the dust is blown all the way across the Atlantic Ocean.

GLOBE schools across a region can cooperate to gain a comprehensive picture of the energy and water cycles within the region and to trace some parts of the biogeochemical cycles. In a watershed, the characteristics measured in the surface water of streams, lakes, and rivers can be measured at a variety of sites. These characteristics are strongly influenced by the microclimate of the region which is quantified by measurements of air temperature and precipitation, the soil character which may vary across the watershed and need to be measured in a number of places, and the land cover. Schools may combine their Landsat images to gain a complete satellite picture of the region and this can become the basis for a comprehensive regional land cover map. The dynamics of the watershed can be studied using GLOBE measurements of specific weather events, soil moisture and infiltration rates, and whatever data are available on the flow rates of the streams and rivers.

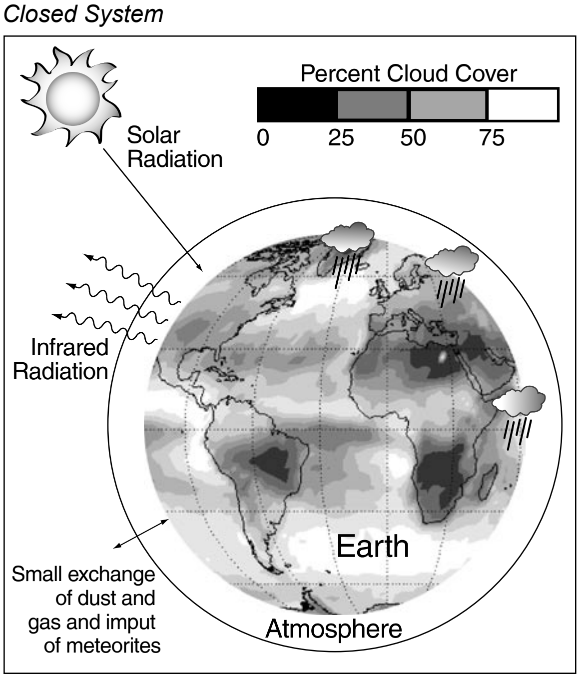
Earth as a System at the Continental/Global Scale

The learning activities in this chapter that are designed to help your students understand the largest spatial scales of the Earth system focus on the continental scale. This is the largest practical scale for meaningful examination of GLOBE data, although it could be considered the largest regional scale. The global scale encompasses the whole Earth, all of the atmosphere, hydrosphere,

Figure EA-I-25: Photograph of the Earth System on the Regional Scale with Inputs and Outputs

pedosphere, cryosphere, and biosphere. If one includes the interior of the planet as well, at this scale, Earth is an almost *closed system* - one in which almost no matter enters or leaves. **Note:** An *isolated system* is one in which no *energy* or matter enters or leaves. See Figure EA-I-26. In fact, the Earth system is closed except for the input of energy from the sun, the balancing loss of energy to space, the extremely small loss of hydrogen from the top of the atmosphere, and the continuous input of gases, dust, and meteorites from space, and the few satellites which we have sent beyond Earth's orbit. Studies of Earth system science also treat the inputs of gases, energy, dust, and lava from Earth's interior and the recycling of material into the crust and upper mantle as external inputs to and outputs from an almost closed system. These exchanges with the interior of the planet tend either to happen on long time scales of tens of thousands to millions of years (geologic time) or to happen almost instantaneously and unpredictably. These latter phenomena, particularly large volcanic eruptions, play havoc with short-term climate predictions.

Figure EA-I-26: Diagram of the Earth as an Almost Closed System



How Do the Local, Regional, and Global Scales Interact?

Within the global Earth system the local and regional scales all contribute to how each of the components (the atmosphere, open waters, cryosphere, soil and terrestrial vegetation) interact with each other as a whole at the global scale. These interactions occur on many different time scales – the characteristic times over which processes or events occur.

All of the GLOBE measurements are taken at the local scale but they sample phenomena with various time scales. The maximum and minimum air temperatures address the daily time scale, while tree height and circumference indicate growth over an annual cycle, and characterization of a soil profile may document the results of thousands of years. Most of the learning activities also involve the local scale and shorter time scales. However, some of the learning activities, such as those in this chapter, broaden your perspective to the regional and global scales to help you understand how local scale environments fit into the regional and global scale contexts. These large scales involve changes over long and short periods. Today GLOBE measurements only cover a few years and primarily contribute to studies of current processes and phenomena. Eventually, as the GLOBE database extends further in time, the measurements will contribute to scientific studies on longer time scales of decades to centuries where there are currently major concerns about global climate change.

The following sections describe the various components of the Earth system in the context of the global scale. Understanding these largest spatial-scale processes will help you more fully understand the context for your local study sites, and how the Earth system connects us all.

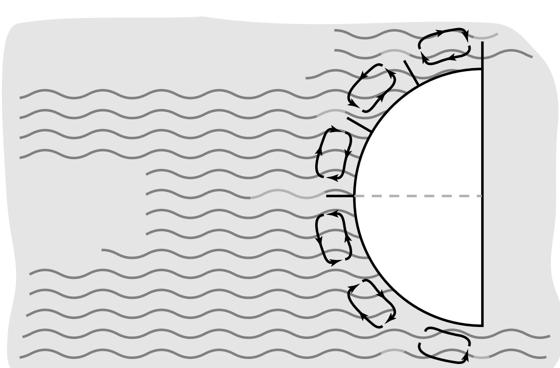
The Earth System Components at the Global Scale: The Atmosphere (Air)

The atmosphere is the gaseous envelope of the Earth. The local properties of the lower atmosphere vary on time scales of minutes to seasons and years. Winds change speed and direction, clouds form and dissipate, precipitation falls, humidity comes and goes, some trace gases such as ozone build up and then go away, and air temperature rises and falls. These local variations are caused by the daily and annual cycles in sunlight and some shifts in ocean circulation such as the El Niño/Southern Oscillation. The overall structure and composition of the atmosphere and the climate change more slowly, on time scales ranging from a decade to millions of years.

As illustrated in Figure EA-I-6. the tropics receive more energy from the sun per unit of surface area than the temperate or polar zones. In fact, even though the warmer tropics radiate more heat to space than high latitude regions, the tropics receive more energy from the sun than they radiate away! Where does this excess energy go? The circulation of the atmosphere and the oceans carries this energy, in the form of heat, to higher latitudes.

If we consider the average north-south motion of the atmosphere, warm air from near the equator rises and moves toward the poles. At roughly 30˚ latitude, the air cools, falls, and moves equatorward near the surface. A similar pattern exists in the polar zones, with air rising at roughly 60˚ latitude and falling at the poles. The tropical and polar zones bracket the temperate zones and drive their circulation patterns. As a result, the air in temperate zones moves poleward at low altitudes, rises at roughly 60˚, returns equatorward aloft and falls at roughly 30˚. The interaction of warm and cold air masses between 30˚ and 60˚ latitude produces the succession of low (storm) and high (fair weather) pressure systems that move from west to east in mid-latitudes. See Figure EA-I-27.

Figure EA-I-27 General Atmospheric Circulation



The Earth System Components at the Global Scale: The Hydrosphere (Bodies of Water)

The hydrosphere encompasses all the bodies of water on Earth including groundwater. At the global scale, it is the oceans and the larger seas that are important. The time scales on which the oceans vary range from a month near the surface, to over a thousand years for deep ocean circulation.

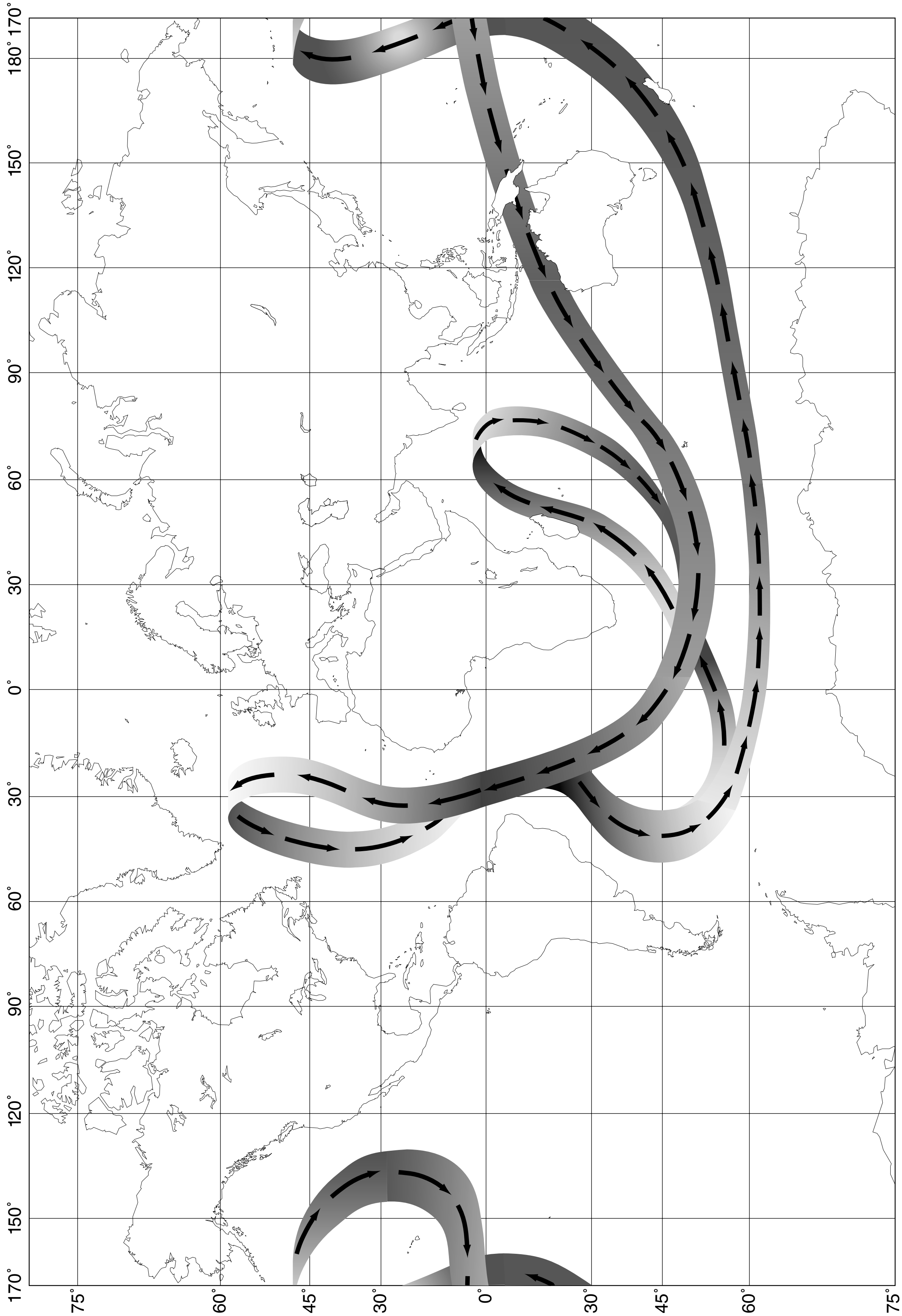
The ocean receives energy from sunlight transmitted through the atmosphere. The *albedo* (reflectivity) of the oceans is relatively low, about 0.1, which means that 90% of the solar radiation falling on the ocean surface is absorbed. The oceans also exchange long wave (thermal infrared) radiation with the atmosphere.

Ocean Circulation

Circulation within the oceans occurs through two basic processes. The first is the horizontal circulation of the upper ocean that is driven by forces induced by surface winds. This surface circulation is coupled to deep ocean circulation (thermohaline) that is driven by differences in the density of seawater due to changes in temperature and salinity. During winter in the polar regions, the ocean surface cools and sea ice forms. As the water freezes, most of the salt is left dissolved in the liquid water. This increase in salinity, particularly in the north Atlantic, causes the surface water to become dense enough to sink and to become bottom water. This bottom water flows toward the equator and eventually returns to the surface. Scientists call this global circulation of ocean waters a conveyor belt which connects the surface and deep waters of the Atlantic, Pacific, and Indian Oceans. See Figure EA-I-28.

The ocean surface is in direct contact with the atmosphere. Large exchanges of aerosols and gases take place at this boundary. Gases that are more abundant in the atmosphere, such as carbon dioxide, are taken up in the ocean water while gases formed in the oceans, such as methyl bromide, are released into the air and are the largest natural sources of some atmospheric trace gases. These processes happen much faster than the thermohaline circulation of the oceans. Today's surface

Figure EA-I-28: The Large Scale Circulation of Water in the World's Oceans, Sometimes Called the Global Conveyor Belt



seawater is in equilibrium with the present composition of the atmosphere, but gases dissolved in bottom water reflect atmospheric conditions from roughly 1500 years ago. Through this gradual overturning of ocean water, gases, such as carbon dioxide, whose atmospheric concentration have increased over the last 1500 years, are gradually taken up by the ocean, lessening their abundance in the air.

Biological Activity

Biological activity is also affected by circulation patterns around the globe. There are areas, for instance, where *upwelling* occurs. Upwelling is the process by which deep, cold, nutrient-rich waters rise to the surface. *Phytoplankton,* microscopic plants floating in the water, form the base of the ocean food chain, and their abundance limits the populations of most other ocean creatures. Where ocean surface waters lack nutrients, growth and reproduction of phytoplankton are limited. Areas where upwelling occurs are generally nutrient-rich and highly productive and have large commercial fisheries.

Biological activity in the oceans plays a major role in the global carbon cycle. Phytoplankton in near surface waters take up carbon through photosynthesis. Some dead organic matter such as shells of microscopic organisms or fecal pellets from animals fall through the water column to the ocean bottom and become buried in sediments. Here in the deep ocean, the carbon in the organic matter is essentially removed from the atmosphere.

The Earth System Components at the Global Scale: The Cryosphere (Ice)

The Role of the Cryosphere in Energy Transfer

The cryosphere is the solid water component of the Earth system. The two main forms of ice are sea ice and continental ice. Either can be covered with snow. Ice has an albedo (reflectivity) that ranges from about 0.5 to 0.8. This is generally higher than what's underneath it. The albedo of newly fallen snow ranges even higher, up to 0.9. So, where covered by ice, Earth's surface reflects more than half the solar radiation falling on it back to space. Ice and snow also insulate Earth's surface, cutting off evaporation which removes a major source of heat to the atmosphere above.

Sea Ice

Sea ice is frozen seawater. If the water is salty, as it is in the ocean and the seas, during the freezing process the salt is left in the water, making the water saltier and denser, and the sea ice less salty. Sea ice floats on the ocean/sea surface and ranges from thin frazzle ice which has just formed and barely coats the surface, to thick ice, which has lasted through many years and may be up to 10 m thick. However the average ice thickness is 3 meters in the Arctic and 1.5 meters around Antarctica. Under the stress of wind and ocean currents, sea ice cracks and moves around. The cracks expose areas of relatively warm ocean water to the cold atmosphere during winter. In winter, this permits a large exchange of energy from high latitude oceans where the water temperature is just about freezing to the atmosphere where air temperatures are well below zero.

Sea ice has a large seasonal cycle and changes on time scales of a few weeks to a few months. The magnitude of these seasonal changes is very sensitive to climate conditions in the atmosphere and oceans, extending the time scales associated with sea ice variations from months to tens of thousands of years–the time scale for ice ages.

Land Ice

Continental ice includes ice sheets such as those in Antarctica (up to 4 km thick) and Greenland (up to 3 km thick), and valley glaciers (generally 10-100 m thick). Most of the fresh water on Earth is frozen in these ice sheets. Continental ice is formed from snow accumulating at the surface and compressing over time into ice. This process is very slow compared to the changes in sea ice. Ice sheets change on time scales ranging from months (for rapidly moving valley glaciers) to tens of thousands of years. These longer changes are associated with ice ages.

Even when frozen, water still flows from the mountains to the oceans. When snow falls in winter, melts in the spring, trickles into a mountain brook, flows into a stream and then a river, and finally into the ocean, the water's journey is completed in a year or less. When the snow falls on a glacier, the journey becomes much longer and lasts for many years. The deep layers of the

Greenland ice sheet which have been sampled with ice cores record conditions when snow fell over 250,000 years ago and are a major source of information about longer-term changes in climate.

The Earth System Components at the Global Scale: The Pedosphere (Soil)

The *pedosphere* is the portion of Earth's land surface covered by layers of organic matter and of weathered rocks and minerals which are less than 2.0 mm in size together with the organisms that live in these layers. The surface temperature of the pedosphere responds quickly to the daily and seasonal cycles in air temperature, changing on time scales ranging from hours to months. The albedo of bare soil averages about 0.3, meaning that 70% of the solar radiation falling on it is absorbed. However, there are many different soil types, so this number varies from place to place and from season to season. The land surface is often covered by vegetation which intercepts the sunlight before it reaches the soil.

Just like the atmosphere and the ocean, there are movements within the pedosphere and lithosphere that act to redistribute the energy received from the sun. Conduction, convection, and radiation processes all operate within the soil to redistribute energy within the soil profile. The rate and amount of distribution depends on soil properties such as the particle size distribution, bulk density, water content, and organic matter content.

The pedosphere forms as a result of the interaction of the five soil forming factors: parent material (the mineral or formerly living material from which the soil is derived), climate (both macro- and micro-climate), topography (including slope, position, and aspect), biota (plants, animals including humans, and all other organisms), and the amount of time for which each of the other factors has interacted. Four major processes occur in response to the soil forming factors: additions, losses, transfers, and transformations. The processes of addition include inputs such as heat and energy, water, nutrients, organic matter, or deposits of materials. Losses of energy and heat, water, nutrients from plant uptake or leaching, and erosion of soil material also take place. Transfers occur when materials within the soil, such as water, clay, iron, plant nutrients, or organic matter are moved from one horizon to another. Lastly, transformations include the change of soil constituents from one form to another within the soil, such as liquid water to ice, large particles to smaller particles, organic matter to humus, and oxidized iron to reduced iron. Each of the five factors and the corresponding four processes produce a localized soil profile with specific characteristics and horizon attributes.

Under well drained conditions, when respiration of organisms and roots in the soil is at its optimum, a great deal of CO_2 is produced. The percentage of CO_2 in the soil can be 10 to over 100 times greater than in the atmosphere above the soil. This soil CO_2 becomes a source to the atmosphere as it diffuses upward to the surface, or is released when the soil is disturbed from plowing or other turnover processes. Respiration is only one source of soil CO_2 to the atmosphere. Soil organic matter decomposition provides another very large pool of CO_2 and CH_4 to the atmosphere.

Nitrogen is the most abundant element in the atmosphere, yet it is not in a form that is available to plants, and is often the most limiting nutrient for plant growth. Soil organisms and certain processes help to convert atmospheric N_2 into a form plants can use. These forms are nitrate (NO_3^-) or ammonium (NH_4^+). Other organisms convert organic forms of nitrogen from plant and animal remains into plant-usable forms. Nitrogen can also be removed from the soil and become a source of nitrogen to the atmosphere and to ground or surface water.

The Earth System Components at the Global Scale: Terrestrial Vegetation (land plants)

Land plants connect the soil and atmosphere. Individual plants form this connection on time scales ranging from a few weeks to over 1000 years. However, land vegetation collectively affects the Earth system on time scales of seasons to thousands of years and longer. As land plants grow they reshape the environment around them. They shade the surface, block the wind, intercept precipitation, pump water from the ground into the air, remove nutrients from soil and some trace gases from air, hold soil against erosion, and litter the ground with leaves and twigs which eventually increase the organic content of the soil. In these ways, terrestrial vegetation plays a significant role in the energy, water, and biogeochemical cycles. The expansion and growth of forests in particular removes carbon dioxide from the atmosphere in significant amounts.

Educational Objectives

Students participating in the activities presented in this chapter should gain scientific inquiry abilities and understanding of a number of scientific concepts. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The Scientific Inquiry Abilities listed in the grey box are based on the assumption that the teacher has completed the protocol including the *Looking At the Data* section. If this section is not used, not all of the Inquiry Abilities will be covered. The Science Concepts included are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. The Geography Concepts are taken from the National Geography Standards prepared by the National Education Standards Project. Additional Enrichment Concepts specific to the atmosphere measurements have been included as well. The gray box at the beginning of each protocol or learning activity gives the key scientific concepts and scientific inquiry abilities covered. The following tables provide a summary indicating which concepts and abilities are covered in which protocols or learning activities.

Budburst Protocol

Students will select trees at a Land Cover Sample Site or Phenology Site and observe budburst.

Green-Up Protocol

Students will monitor the budburst and growth of leaves of selected trees, shrubs or grasses.

Green-Down Protocol

Students will use a GLOBE Plant Color Guide to monitor the change in color of selected leaves of trees, shrubs or grasses.

*Ruby-throated Hummingbird (RTHU) Protocol***

Students will observe the arrival and departure of Ruby-throated Hummingbirds, monitor hummingbird visits to flowers and feeders, and observe nesting behavior.

*Lilac Phenology Protocol**

Students record the five pheno phases of either common or clonal lilac plants.

*Phenological Gardens Protocol***

Students plant a garden and observe the flowering and leaf development stages of specified plants throughout the year.

*Seaweed Reproduction Phenology Protocol**

Students collect specified seaweed species and observe the reproductive phenological phases of the seaweed.

*Arctic Bird Migration Monitoring Protocol**

Over the year, students observe when specified migratory bird species first arrive and count their numbers until few or none of them remain.

* See the full e-guide version of the Teacher's Guide available on the GLOBE Web site and CD-ROM.

** Separate print version available on request to schools in the areas where the protocol may be conducted. The protocol and related material are also available in the e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction

Why Study Phenology?

Each year, as conditions for plant growth improve, a wave of green spreads over the land surface (green-up) and then retreats as conditions for plant growth decline (green-down). These waves are important because they are directly related to global carbon fixation and the amount of carbon dioxide (CO_2) in the atmosphere. The period between green-up and green-down or *senescence* is known as the *growing season*, and changes in the length of the growing season may be an indication of global climate change. For example, some scientists recently found that the growing season has increased in northern latitudes by eight days since the early 1980s. However, their conclusion is controversial because it was based only on satellite data. On-the-ground observations of plant green-up and green-down are needed to validate these types of satellite estimates.

Why Take Phenology Measurements

Estimates based on remote sensing data from satellites vary because of problems such as interference from small and large clouds, atmospheric haze, and other atmospheric properties that affect the greenness values that satellites detect. Other problems such as low sun angles at high latitudes, change of sun angle with seasons, poor viewing geometry, and aging of satellite detectors can affect scientist's estimates of greenness as well. GLOBE student observations are the only global network of ground-based plant phenology observations and will help scientists validate their estimates of global growing season changes that they derive using satellite data.

The Big Picture

Phenology is the study of living organisms' response to seasonal and climatic changes in their environment. Seasonal changes include variations in day length or duration of sunlight, precipitation, temperature and other life-controlling factors. The focus of this investigation is plant phenology during green-up and green-down. The plant growing season generally corresponds to the period between green-up and green-down. Green-up and green-down can be used to examine regional and global vegetation patterns, year-to-year trends, and vegetation responses to climate change.

Plant green-up is initiated when *dormancy* (a state of suspended growth and metabolism), is broken by environmental conditions such as longer hours of sunlight and higher temperatures in temperate regions, and rains and cooler temperatures in deserts and semi-arid areas. As plants begin green-up, leaf chlorophyll absorbs sunlight for photosynthesis. Photosynthesis fixes carbon dioxide from the atmosphere, using the carbon atoms to form plant tissue. To help in developing computer models of atmospheric carbon dioxide, scientists need accurate information about the timing and duration of global greenness (when photosynthesis is actively going on during daylight). This is especially important because the length of the plant growing season seems to have increased dramatically in some parts of the globe. Monitoring the length of the growing season is important for detecting climate change and for understanding the carbon cycle – one of the key biogeochemical cycles discussed in the introduction.

As plants photosynthesize, they also transpire water from the soil, through the roots and plant stems, and out the leaves into the atmosphere. This affects atmospheric temperature and humidity, and soil moisture. With green-down, plant transpiration of water decreases; plants reduce water loss when their water supply is greatly limited during winters for deciduous plants and during dry spells for desert plants. Therefore, knowing the timing of green-up and green-down is important for understanding the global water cycle. Scientists also use greenness estimates from satellites to map wild fire danger. High greenness areas represent lower wildfire danger, while low greenness areas represent higher wildfire danger. Scientists studying migrations of animals such as caribou use greenness maps to help them understand animal population migration patterns.

As discussed in the *Land Cover/Biology Investigation,* healthy green plants reflect much more near-infrared sunlight than visible light. Remote sensing scientists use visible and near-infrared reflectance estimates from satellites to derive a greenness index. New and better satellite data are now available from the MODIS (Moderate Resolution Imaging Spectrometer) instrument on board NASA's Terra satellite launched in December 1999. This satellite is part of a coordinated international effort to use many satellites and instruments to study the global environment. However, scientists will need GLOBE student observations of plant phenology to help them validate estimates of greenness from around the world taken by these and other satellite systems.

Measurement Logistics

GLOBE supports three plant phenology protocols: Budburst, Green-up, and Green-down. The *Budburst* and *Green-up Protocols* are related but are designed for different situations. Green-up and Green-down have the same site requirements. The *Budburst Protocol* is more appropriate if one or more of following conditions is met.

1. Students cannot reach the buds on the trees to measure the lengths of the leaves with a ruler as is required for Green-up.
2. Your school will be on summer vacation before the full sequence of Green-up is complete. This can occur for schools located in very cold climates where spring growth begins late in the year. (If time permits, students could do the Green-down in the autumn when school is in session.)
3. The teacher does not want to commit to the added time required for Green-up. Green-up and Green-down allow for a more in-depth and quantitative analysis of plant phenology.

Protocol	Budburst	Green-Up	Green-Down
What procedures are performed?	Observe and report dates of green-up	Observe and report dates of green-up and leaf growth	Observe and report dates of green-down color changes
Where are procedures conducted?	Plant Phenology Study Site; Site close to Atmosphere and Soil Moisture and Temperature Study Sites is preferred		
When are procedures conducted?	Twice weekly, starting at least two weeks before estimated initial budburst, then daily until budburst is seen on three places on tree	Twice weekly, starting at least two weeks before estimated initial budburst until leaf length stops increasing	Twice weekly, starting two weeks before estimated initial green-down until leaf color change is complete or leaves fall off
What equipment is needed?	Data sheets, plant identification keys	Permanent marker, ruler with mm scale, compass, camera, Data Sheets, plant identification keys, calculator (optional)	Permanent marker, GLOBE Plant Color Guide, compass, camera, plant identification keys, Data Sheets

Educational Objectives

Students participating in the activities presented in this chapter should gain inquiry abilities and understanding of a number of concepts. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The *Scientific Inquiry Abilities* listed in the gray box are based on the assumption that the teacher has completed the protocol including the *Looking At The Data* section. If this section is not used, not all of the Inquiry Abilities will be covered. The *Science Concepts* included are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. The *Geography Concepts* are taken from the National Geography Standards prepared by the National Education Standards Project. Additional *Enrichment Concepts* specific to the hydrology measurements have been included as well. The gray box at the beginning of each protocol or learning activity gives the key concepts and scientific inquiry abilities covered. The following tables provide a summary indicating which concepts and abilities are covered in which protocols or learning activities.

National Science Education Standards: Phenology

National Science Education Standards	Protocols				
	Budburst	Green-up	Green-down	Humming-birds	Phenological Gardens
Earth And Space Sciences					
Changes in the Earth and Sky (K-4)					
Weather changes from day to day over the seasons.	■	■	■	■	
Weather can be described by measurable quantities				■	
Properties of Earth Materials (K-4)					
Soils have properties of color,k texture and composition; they support the growth of many kinds of plants.					
Structure of the Earth System (5-8)					
Soil consists of weathered rocks and decomposed organic matter					
Water circulates through the biosphere, lithosphere, atmoshpere and hydrosphere (water cycle)					
Energy in the Earth System (9-12)					
The sun is the major source of energy at Earth's surface	■	■	■	■	
Life Sciences					
The Characteristics of Organisms (K-4)					
Organisms have basic needs.		■	■	■	■
Organisms can only survive in environments where their needs are met	■	■	■	■	
Earth has many different environments that support different combinations of organisms		■	■	■	
Organisms and their Environments (K-4)					
Organisms' functions relate to their environment		■	■	■	■
Organisms change the environment in which they live	■	■	■		
Life Cycles of Organisms (K-4)					
Plants and animals have life cycles	■	■	■	■	■
Plants closely resemble their parents					■
Regulation and Behavior (5-8)					
All organisms must be able to obtain and use resources while living in a–constantly changing environment				■	■
The Interdependence of Organisms (9-12)					
Organisms both cooperate and compete in ecosystems				■	
The population of an ecosystem is limited by its resources				■	
Matter, Energy, and Organization in Living Systems (9-12)					
Energy for life derives mainly from the sun	■	■	■		■
Living systems require a continuous input of energy to maintain their chemical and physical organizations	■	■	■		■
The Behavior of Organisms (9-12)					
The interaction of organisms in an ecosystem have evolved together over time				■	
Geography					
The World in Spatial Terms (K-12)					
Plants help to define the character and spatial distribution of ecosystems on the Earth's surface.					■

Budburst Protocol

Purpose

To observe budburst on selected trees at a Land Cover Sample Site, or a designated Phenology Site

Overview

In places where there are trees, students will select at least two trees and observe when budburst occurs.

Student Outcomes

Students will be able to,

- observe when buds burst open at the beginning of the growing season;
- examine relationships between budburst and climate factors;
- communicate project results with other GLOBE schools;
- collaborate with other GLOBE schools (within your country or other countries);
- share observations by submitting data to the GLOBE archive;
- compare phenological patterns among species; and
- predict the timing of budburst for upcoming seasons (advanced).

Science Concepts

Earth and Space Sciences

Weather changes from day to day over the seasons.

The sun is a major source of energy at the Earth's surface.

Life Sciences

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environments.

Organisms change the environment in which they live.

Plants and animals have life cycles.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Estimate dominant plant species.

Identify plant species (advanced).

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

Selection of site and trees (not including times to and from site): 1 hour

Daily visits (not including times to and from site): 15 min

Level

All

Frequency

Initially, twice a week beginning two weeks prior to anticipated budburst. After leaves start to emerge, daily visits until budburst is observed.

Materials and Tools

Budburst Data Sheet

Budburst Site Definition Sheet

Budburst Site Definition Field Guide

Budburst Field Guide

GPS Protocol Field Guide (if using a new site)

GPS Protocol Data Sheet (if using a new site)

Binoculars (optional)

GPS receiver (if using a new site)

Local tree identification guide

Preparation

Review how to determine the dominant tree species in a *Land Cover Sample Site* in the *Land Cover/Biology Investigation.*

Familiarize students with the local tree identification guides.

Prerequisites

None

Teacher Support

Who can do the Budburst Protocol?

First, you must decide if you live in an area appropriate for the GLOBE *Budburst Protocol*. You must live in an area with trees. Both deciduous and evergreen trees have buds, so either type may be used. Areas dominated by shrub and bush vegetation also have phenology, but the annual patterns are so variable that accurate monitoring takes more time. If you live in a tropical area with a normally warm and wet climate, your vegetation may not have strong annual vegetation cycles. However, if you have a distinct dry season and most of the vegetation loses its leaves during the dry season, you should definitely participate. You probably live in the part of the world for which we have a very poor understanding of vegetation phenology.

Budburst is one of three plant phenology protocols. For a discussion on which protocol is more appropriate for your class, please look at the *Measurement Logistics* section in the *Introduction* section to the *Phenology Protocols*.

Site Selection

For your site selection, you have different options.

1. A convenient option would be to use a preexisting Land Cover Sample Site if frequent observations at such a site are practical.
2. Create a new Budburst Study Site. Since students will need to make many visits to the site, we suggest you select a site close to your school or to where students live. You may use your school grounds or any other site that includes native trees that are minimally watered or fertilized. Identify the latitude, longitude and elevation following the GLOBE *GPS Protocol*.

You want to observe trees that are as close to the general vegetation as possible. If you live in an area where most of the trees are watered or fertilized, then observing an irrigated tree is fine. However, if most of the trees are growing without irrigation, do not pick a watered tree for study.

Since the results of this protocol will be combined with temperature and precipitation data from the GLOBE *Atmosphere Investigation,* try to choose a site close to the Atmosphere Study Site.

Tree Selection at Your Site

Budburst measurements are quick and easy. Consequently, you can either take just a few minutes a day to make observations or you may try to design a more in-depth investigation. Based on your available time and interest, select one of the following three measurement strategies:

1. Budburst for the dominant overstory species.
If you are using a Land Cover Sample Site, select the dominant tree species in the canopy. If you are using a new site, visually inspect the canopy and estimate which species is dominant. Estimate coverage when plants are in full leaf. If you are selecting a site when leaves are not full, do the best you can to estimate which tree species would have the most canopy coverage. If you are in an area where two or more species are equally dominant, chose one of the species and record this information as metadata in the comments section in the *Budburst Data Sheet*.

2. Budburst for more than one overstory species.
If you would like to study the phenological patterns of different species, additional trees may be identified for budburst analysis.

3. Budburst for overstory and/or understory species.
In many forests or parks, there are two levels of woody plants (like trees or shrubs). Woody plants living underneath the highest layer of trees are called the understory. They often have a very different phenological cycle than do overstory plants. These understory plants, which may be shrubs or small trees, can also be measured. If your shrub or tree is living underneath the top layer of trees, it is considered to be an understory plant. This information should be entered in the metadata section of your *Budburst Site Definition Sheet*. The phenological difference between understory and overstory vegetation is scientifically important and schools are encouraged to measure both if possible.

Once you have decided on the measurement you wish to take, you need to decide which trees to observe. Observe at least two trees and numerically label each tree. The trees you select should meet several criteria:

- Trees should be easily accessible.
- Ideally, individual buds should be visible with the naked eye. Otherwise, binoculars may be used to observe the individual buds.
- If possible, select native tree species. Non-native species, called exotics, have phenological cycles that are not necessarily tied to the local climate. Fruit trees are a classic example. You may have heard on the local news that a late spring frost ruined a fruit crop in your area. Often this is because exotics have not evolved to survive in the local climate. If you are unsure which plants are natives, ask your teacher, a local greenhouse or agricultural extension agent, or the appropriate staff at a local college or university.

Measuring Budburst

The timing of budburst on individual branches can vary by several days within one tree. High branches also can be difficult to see. For these reasons, using the steps below, you will record the date on which budburst has occurred on at least three different areas of the tree.

- Since budburst is highly variable from year to year, you will need to start monitoring well before the average date of budburst. Ask a biology teacher or someone from your local community if they have any record of budburst for your area. You can try contacting local horticultural societies, or college or university biology departments. The date does not need to be exact. You are just trying to establish when, on average, leaves begin to appear.
- In the spring, two weeks or more before the average date of budburst, the entire class or at least all students who will be taking measurements, should visit the Budburst Study Site to determine which trees to monitor.
- Make trips to your site initially twice a week. Look at the buds all over the tree. Do the buds appear to be swelling or have any of the buds burst open? Can you see signs of tiny leaves emerging from inside the bud? If so, this is the beginning of the overall tree budburst and you should start visiting the site every day. When you have noticed three separate locations on the each tree where budburst has occurred, enter this as the date of budburst on the *Budburst Data Sheet*. Three buds on one branch do not count; you are looking for three different parts of the tree where budburst has happened. You should have one date for each tree.
- Budburst observations can be made at any time during the day.

Managing Students

It is very important that someone visits the site at least twice a week until budburst begins to occur. After this, make observations every day in order to accurately estimate the day when three parts of the tree have experienced budburst. Depending on how rapidly budburst occurs, this could mean many visits to the site; sharing this responsibility among several students should make this easier to accomplish. Try to make a schedule so that students can take turns visiting the site with their parents or another adult if necessary. This will lessen the chance of not visiting the site often enough. By reporting the date of the last observation before budburst occurred, everyone using your data will know how many days are missing (if any) immediately preceding the date of budburst and therefore of the time interval when budburst occurred.

Frequently Asked Questions

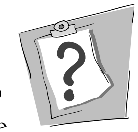
1. What happens when the tree I am observing is cut down or dies?

If a tree dies or is cut down, select another tree of the same species. Identify the new tree with the next number in your labeling sequence, for example, 'tree 3'. Record the changes in tree selection as metadata.

2. Can we record more than one budburst measurement for the same Budburst Study Site?

Yes, as long as all the trees are within a 30 m x 30 m area you may use the same Budburst Study Site for all the trees. If you are observing trees outside a 30 m x 30 m area you will need to define another Budburst Study Site.

3. What is meant by three separate locations on each tree?



The purpose of this requirement is to avoid recording budburst of a single bud that does not represent the overall phenological development of the tree. You need to wait until you see at least one individual budburst on three separate places on the tree. Three budbursts on one branch does not count. Beyond this, you do not need to worry about height of the branches, orientation, or shading.

Budburst Site Definition
Field Guide

Task

To select one or more native trees in the canopy, identify the species and locate the latitude, longitude and elevation. Trees or shrubs in the understory can be selected too.

What You Need

- ❑ GPS receiver
- ❑ *GPS Field Guide*
- ❑ *GPS Data Sheet*
- ❑ *Budburst Site Definition Sheet*
- ❑ Pen or pencil
- ❑ Local tree identification guide
- ❑ Flagging Tape

In the Field

1. Fill out the top part of the *Budburst Site Definition Sheet.*
2. Use the GPS receiver and *GPS Data Sheet* to identify the latitude, longitude and elevation. You do not need to do this if using a defined Land Cover Sample Site.
3. Identify the dominant tree species. Record the genus and species.
4. Put flagging tape on the trees you selected.
5. Complete the comment section on the *Budburst Site Definition Sheet.*

Budburst Protocol
Field Guide

Task

To observe budburst on three locations on your tree

What You Need

- ❑ Binoculars (optional)
- ❑ Pen or pencil
- ❑ *Budburst Data Sheet*

In the Field

1. About two weeks before budburst visit Budburst Site and observe selected trees. Record date. Are there tiny green leaves emerging anywhere on one or both trees?
   a. If yes, start to observe trees each day. Go to step 2.
   b. If no, continue to visit site twice a week.
2. Each day observe trees until budburst can be seen on three locations in each tree. Record dates.

Budburst Protocol –Looking at the Data

Are the data reasonable?

Even though the timing of budburst varies among years, budburst occurs when trees sense temperature or moisture conditions that act as signals or "triggers". In other words, the trees respond to the local environmental and not to the dates on a calendar. Moisture and temperature will affect the timing of budburst.

Budburst tends to show some general patterns that you can use to assess whether or not your data are reasonable. In general, budburst can vary by about one month from year to year. If your school records indicate that budburst occurred on March 1 in one year and June 30 in the next, this indicates a possible data entry error. For the same species, trees growing farther north tend to have a later budburst than more southern trees (for the northern hemisphere). Microclimates can also affect budburst. Trees on the north side of buildings or in topographic low spots will probably experience colder temperatures and be characterized by a later budburst. By setting up your own budburst measurements, you can test these kinds of phenomenon.

What do scientists look for in the data?

GLOBE data will be used to better understand how satellite data correspond to real ground conditions. Additionally, by using your observations of budburst along with your temperature and precipitation data, scientists will be able to accomplish several objectives. After mapping the annual dates of budburst across the continents and establishing weather patterns that control phenology in your area and across the world, scientists can examine the relative importance of temperature and moisture on the beginning of the growing season. Eventually, scientists will be able to map areas of the world where the growing season is controlled by temperature and where it is controlled by moisture. Over time, scientists will develop a better understanding of how global vegetation responds to inter-annual climate variability. This understanding of plant phenology is a critical component of computer models of the global climate system.

Here is an example of how scientists investigate the relationship between timing of budburst and climate conditions. To do this, you need the temperature and precipitation data preceding budburst so that you can estimate the amount of moisture available for the trees and how warm the conditions are.

Estimating Warming Conditions: Calculating Growing Degree Summation:

Many plants in different areas of the world require a set amount of warming to initiate growth and to minimize their risk of frost damage. Growing degree summation (GDS) is a common measure of warming used by scientists. For this method, you will need the maximum and minimum temperature data for your school from January 1st (if you live in the northern hemisphere) or July first (if you live in the southern hemisphere) up to and including the date of budburst. To calculate GDS:

1. First, for each day, calculate the daily average temperature (Tavg) by adding the maximum and minimum temperature for each day and dividing by two beginning on January 1 in the northern hemisphere and July 1 in the southern hemisphere.
2. Starting with January 1 or July 1, check to see if Tavg is greater than 0˚ C. If it is, record this temperature. If not, ignore it. Go to the next day. Again, check to see if the (Tavg) is greater than 0˚ C. If it is, add it to the temperature you recorded for the first. If not, again ignore it. Repeat this process for each subsequent day up to the day of budburst. The sum of the positive average temperatures is your GDS. Record value in Table EA-BB-3 on your *Work Sheet.*

For example, look at the following series of temperatures and the summation that would go with them:

Tavg (0˚ C):	-3	-2	2	3	-1	5	6
GDS:	0	0	2	5	5	10	16

Calculating Moisture Availability

Moisture availability is often measured by comparing the input of water to the surface with the amount of water that could leave the surface. In other words, inputs are compared with outputs. If inputs exceed potential outputs, the environment is moist. On the other hand, if potential outputs are much larger than inputs, drought conditions exist. The precipitation (both solid and liquid) measured at your school is the input. Outputs are evaporation and transpiration. Transpiration is the process of water loss from plants while they absorb CO_2 for photosynthesis. The sum of evaporation and transpiration is called **e**vapo**t**ranspiration, or ET. ET can be accurately estimated using fairly complicated equations. For this activity, a reasonable estimate can be made using a very simple method to calculate a related quantity: the potential amount of water that could leave the surface under the observed temperature and precipitation conditions. This is called **p**otential **e**vapo**t**ranspiration, or PET. The following steps show you how to calculate the input, output and moisture availability.

Inputs

1. To calculate inputs, you need to sum the daily precipitation values for the 29 days prior to budburst and the day of budburst (a total of 30 days). This includes the rainfall and the liquid-water equivalent of new snow. You can record your values for the 30 days in Table EA-BB-2 in the student data work sheet. Record the total value in Table EA-BB-3.
2. If snow was on the ground at the time of budburst, then you need the liquid-water equivalent of the total snow depth. Record the value in Table EA-BB-3.
3. If snow was on the ground on the 29th day before budburst, you need a measurement or estimate of the liquid-water equivalent of the snow pack for that day. This can be done easily by making a linear interpolation between the two dates closest to the 29th day before budburst. On a piece of graph paper plot the two known values; the date is on the x-axis, the water equivalent in mm is on the y-axis. Draw a straight line between the two points. Locate the date needed and find the corresponding y-value on the line. This will give you an estimate of the liquid-water equivalent of the snow pack for the 29th day prior to budburst. Enter the value in Table EA-BB-3.
4. Total input of water = sum of the rain + sum of the water equivalent of new snow + water equivalent of snow pack on the 29th day prior to budburst - water equivalent of snow pack on the day of budburst. Record the result of your calculation in Table EA-BB-3.

Outputs:

To estimate potential evapotranspiration (PET), we will rely on the concept that for a given temperature, air can only hold a certain amount of water. Warmer air can hold more water. This means that under warm conditions, PET is higher than under cold conditions. In reality, PET also depends on the amount of solar radiation, but we can still obtain useful estimates using only temperature. Table EA-BB-1 includes calculations of PET based on your measured temperature and a simple mathematical model.

1. Once you have detected budburst, use Table EA-BB-1 to get PET. For the day of budburst, find Tavg in Table EA-BB-1. Then look in the column to the right. This is PET in mm per day. Record this value with its corresponding date in Table EA-BB-2 on the student work sheet. Since plants respond to long-term moisture trends, record PET for the 29 days prior to budburst so that you have a total of 30 values of PET.
2. Sum the PET values for the 30 days recorded in Table EA-BB-2. Enter the 30-day total in Table EA-BB-3.

Water Difference:

1. Subtract the PET total from either the precipitation total or the total water inputs, if the liquid-water equivalents of snow pack are part of your calculations. We will call this the water difference (WD). If WD is positive, this indicates wet conditions. Negative WD values suggest dry conditions.
2. Record the value in Table EA-BB-3.

Table EA-BB-1

Tavg (˚C)	PET (mm)	Tavg (˚C)	PET (mm)
-20	0.15	16	2.3
-19	0.16	17	2.4
-18	0.18	18	2.5
-17	0.19	19	2.7
-16	0.21	20	2.9
-15	0.23	21	3.0
-14	0.25	22	3.2
-13	0.27	23	3.4
-12	0.30	24	3.6
-11	0.32	25	3.8
-10	0.35	26	4.0
-9	0.38	27	4.3
-8	0.42	28	4.5
-7	0.45	29	4.7
-6	0.49	30	5.0
-5	0.54	31	5.3
-4	0.58	32	5.6
-3	0.63	33	5.9
-2	0.68	34	6.2
-1	0.74	35	6.5
0	0.8	36	6.9
1	0.9	37	7.2
2	0.9	38	7.6
3	1.0	39	8.0
4	1.1	40	8.4
5	1.1	41	8.9
6	1.2	42	9.3
7	1.3	43	9.8
8	1.4	44	10.3
9	1.5	45	10.8
10	1.6	46	11.3
11	1.7	47	11.9
12	1.8	48	12.4
13	1.9	49	13.0
14	2.0	50	13.7
15	2.1		

Budburst Data Analysis

Work Sheet

List of Abbreviations:

GDS: growing degree summation

PET: potential evapotranspiration

Tavg: average temperature

WD: water difference

Observations:

GDS: The summation of values (temperature values above 0° C) between and including January 1 (northern hemisphere) or July 1 (southern hemisphere) and the day of budburst If the difference in elevation between your Atmosphere and Phenology Sites is greater than 500 meters, then you need to add a correction factor. This is 6° C for every 1000 meters (colder at higher elevations). For instance if the budburst site is 500 meters higher than the closest atmosphere site, you would subtract 3° C for each day with a value above 0° C and then sum all the new values above 0° C. Table 2 can be used for calculating PET and precipitation. The totals are the summations of the values for 30 days (29 days before budburst and the day of budburst). Tavg for each day is the sum of the daily maximum and minimum temperatures divided by 2. It may be easier to start with the day of budburst and work backwards for the 30 days.

If you have calculated the water equivalent of snow pack in the *Solid Precipitation Protocol* in the *Atmosphere Investigation*, you need the values of the water equivalents of the snow pack for the day of budburst and the 29th day before budburst for each branch.

Total Water Inputs = Precipitation, *or*

= Precipitation + water equivalent 29th day prior - water equivalent at budburst

Water Difference (WD) = Total Water Inputs - PET

Table EA-BB-2

Day	Tavg (° C)	PET (mm)	Precipitation (mm)
Total	no total needed		

Table EA-BB-3: Phenology Data

					Water Equivalent of Snow Pack				
Tree	Budburst Date (YYYY/MM/DD)	GDS (° C)	PET (mm) A	Precipitation (mm) B	Start (-29 days) (mm) C	End (at budburst) (mm) D	Total Inputs (mm) E (B+C-D)	WD (mm) B-A or E-A	Missed Observations (days)

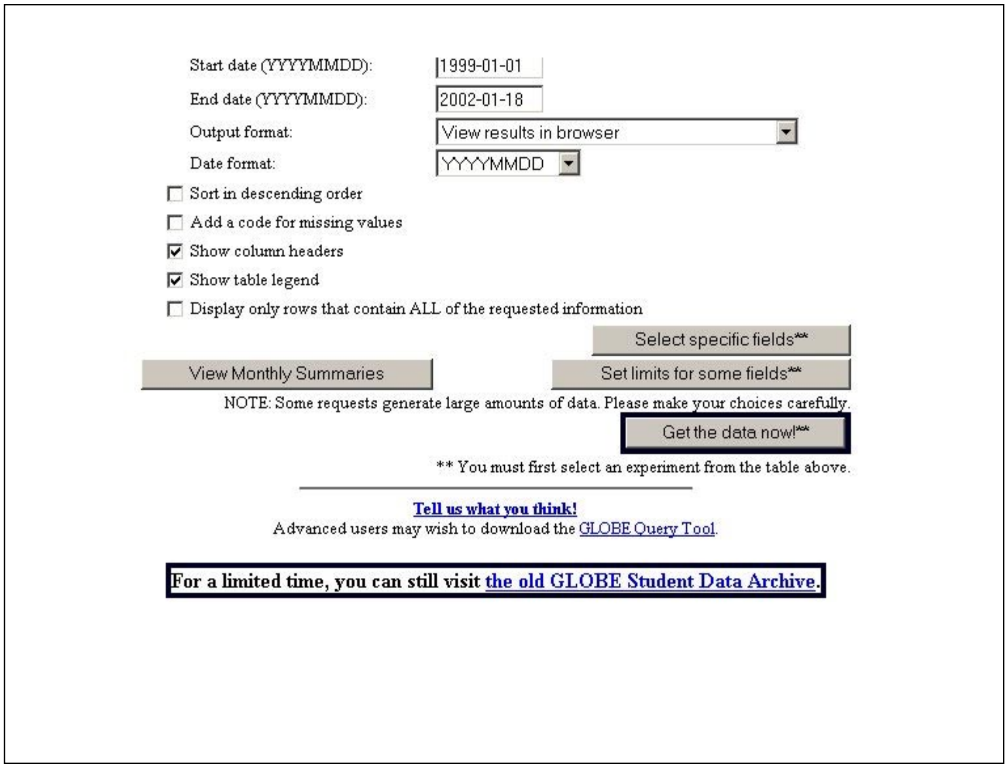
An Example of Student Research

Students in an Earth science class were assigned to do a project on phenology. So far, their class had not collected budburst data, but they intended to start this spring. To better understand the relationship between climate factors (particularly, temperature, precipitation and budburst), they decided to look at GLOBE data on the Web site. They predicted that budburst will occur earlier in warmer years and that it will occur earlier in years with more moisture. They first searched for a school on the Web site that had collected budburst data as well as consistently collected temperature and precipitation data so that they can estimate the warming conditions and moisture availability.

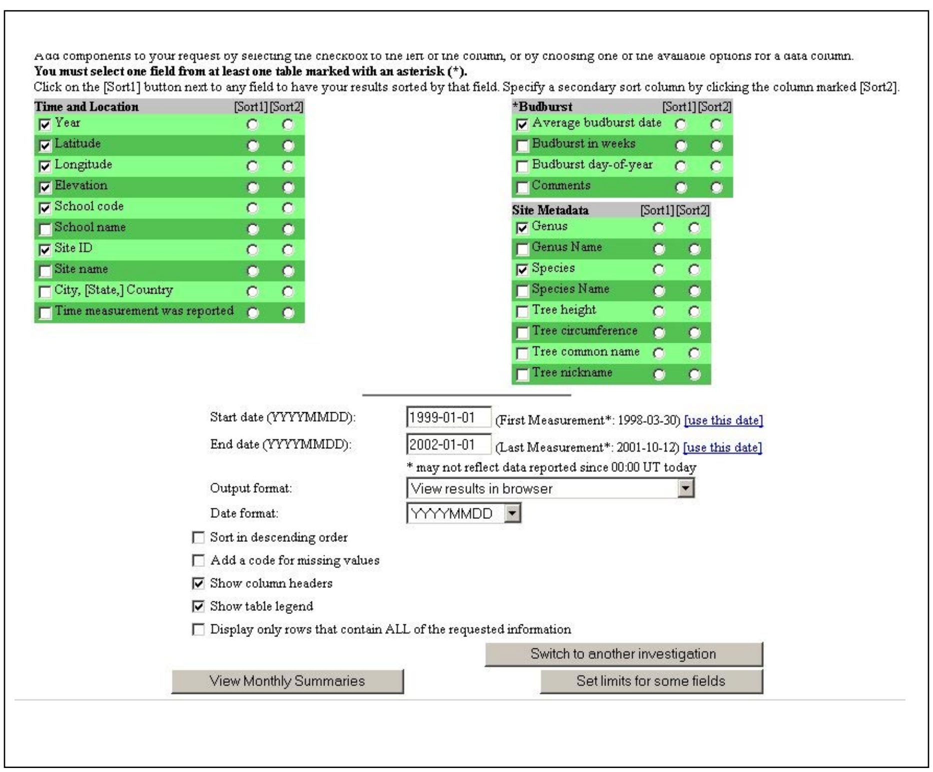
The students went to the data access page and selected "phenology" and entered the dates Jan. 1, 1999 and Jan. 1, 2002, as shown below:

Select an investigation, then press "Select specific fields" to specify the types of data you wish to retrieve, or press "Get the data now!" to get a pre-selected set of columns. [Help]

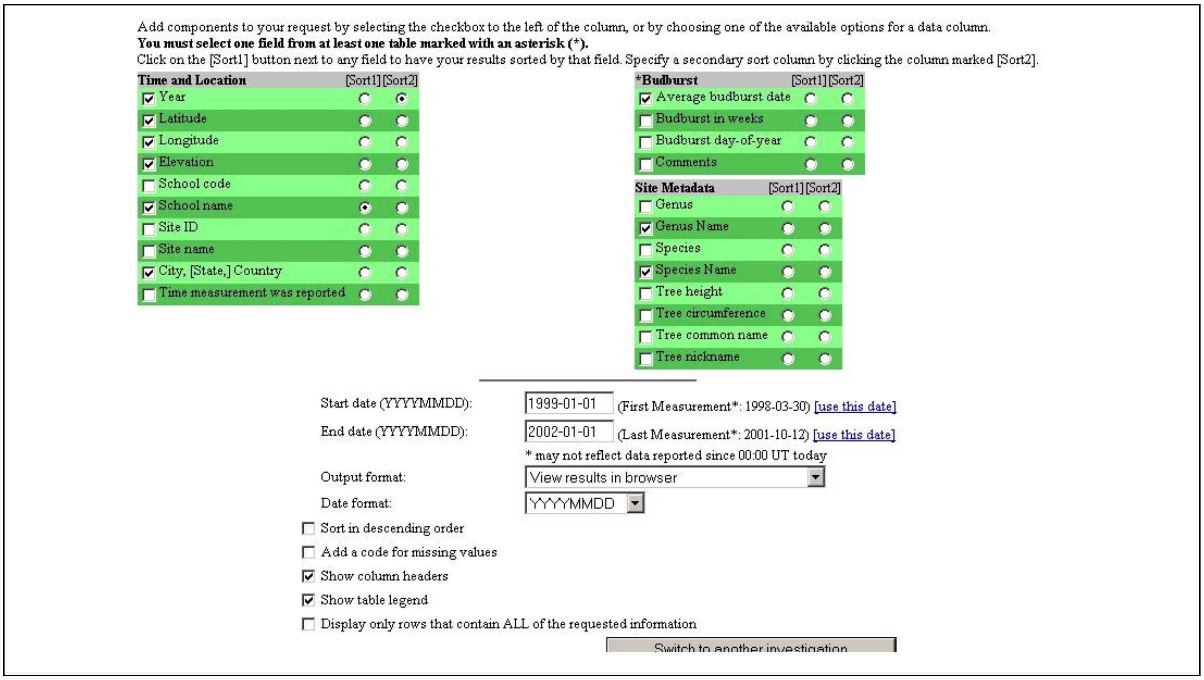
Investigation	First Measurement*	Last Measurement*	Measurements*	Schools*
All Measurements	1995-01-01	2002-01-27	7351385	5098
Atmosphere	1995-01-01	2002-01-27	6390075	4529
Air Temperature	1995-01-01	2002-01-27	2449014	4050
Cloud Observations	1995-01-01	2002-01-27	1777947	4411
Liquid Precipitation	1995-01-01	2002-01-27	1053441	4019
Solid Precipitation	1995-01-01	2002-01-27	1055716	3421
Humidity	1995-02-02	2002-01-27	33329	363
Ozone	2000-08-16	2002-01-24	4294	19
Aerosols	2000-07-02	2002-01-22	2649	9
Barometric Pressure	1995-02-02	2002-01-27	13685	189
Surface Water	1995-01-02	2002-01-26	638909	1806
Soil Moisture	1995-02-21	2002-01-25	58823	215
Soil Moisture (profile)				
Soil Moisture (by depth)				
Soil Temperature	1997-01-01	2002-01-26	71806	205
Soil Temperature (profile)				
Soil Temperature (by depth)				
Soil Characterization	1998-05-18	2002-01-23	10308	156
Soil Infiltration	1997-02-17	2001-11-24	1910	26
Land Cover/Biology	1995-04-19	2002-01-25	115827	642
Tree Biometry	1995-04-23	2001-11-26	42702	500
Grass Biometry	1995-05-16	2001-11-26	69716	238
Land Cover	1995-04-19	2002-01-25	3409	345
Phenology - Budburst	1998-03-30	2001-10-12	2021	100
Phenology - Lilacs	2000-03-25	2001-08-21	251	20
Lilacs (Common)				
Lilacs (Clonal)				
Green-up/Green-down	1999-09-26	2001-12-06	6048	18
Green-up	1999-09-26	2001-12-06	6048	18
Green-down	1999-09-26	2001-12-06	6048	18
Site Location	1996-10-19	2002-01-27	19749	2446
Go **Site Photos** Site photos are viewed using the GLOBE Site Photo viewer.	1995-04-19	2001-10-29	2031	98
[Metadata]	1995-05-01	2002-01-25	35658	2165



They then clicked on the "select specific fields" and a new page came up. The top of the web page was the same as before. However, the bottom of the page had different options from which to choose.



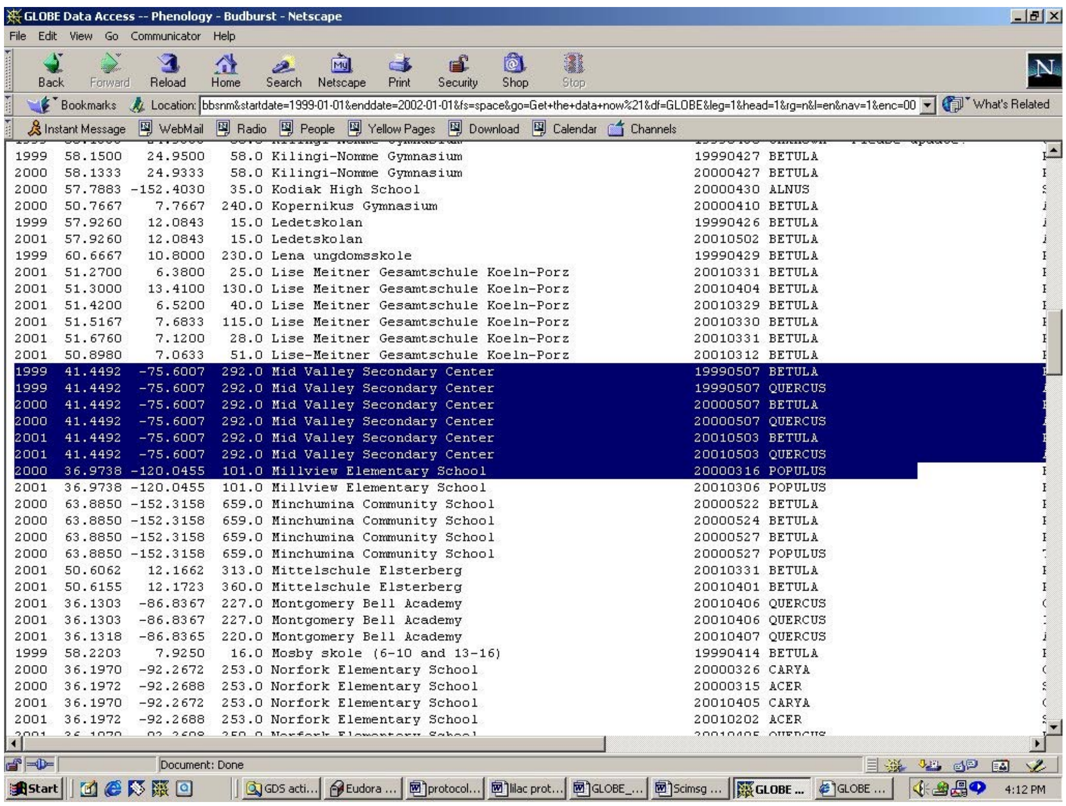
The students selected the columns they wanted to see (year, latitude, longitude, elevation, school name, average budburst date, genus name, and species name). Under the "sort 1" column, they selected "name of school" and under the "sort 2" column, they selected "year". By doing this, the data are organized so that they could quickly scan through the data to see which schools have three years of budburst data. They found two such schools - Vestvaagoey videregaaende skole and Mid Valley Secondary Center.



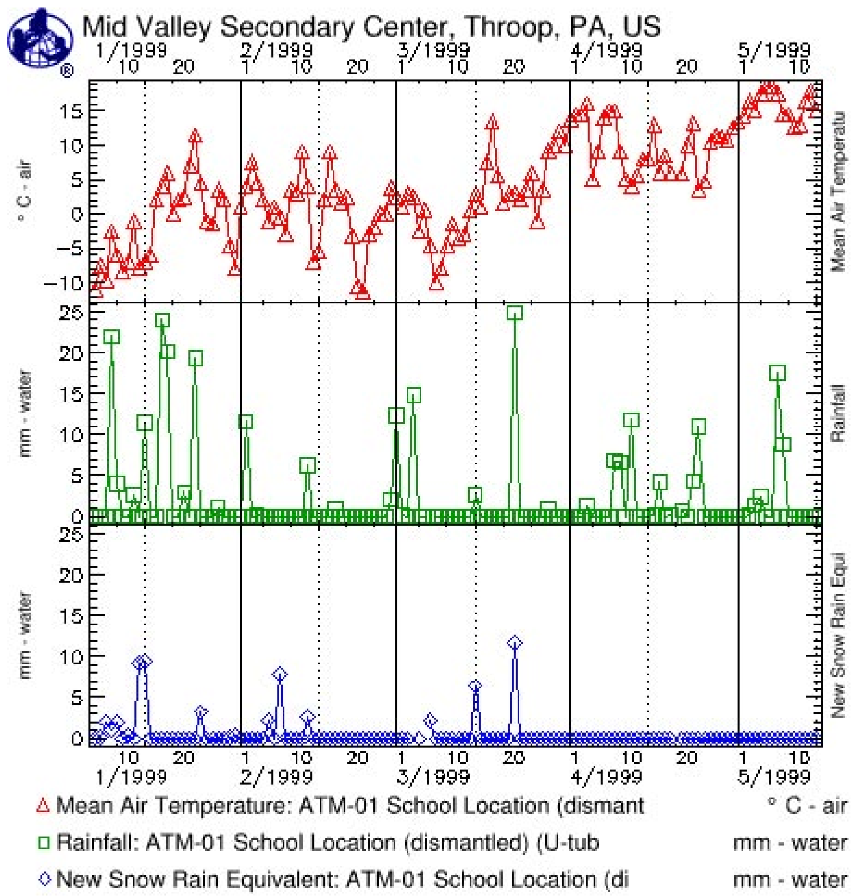
The students chose to examine Mid Valley Secondary Center and wrote down the tree species, *Betula populifolia* and *Quercus alba,* and the dates of budburst for each year.

Next, they needed the school's atmosphere data. At the navigation bar, they clicked on "Schools" under "GLOBE PARTNERS" and typed in "Mid Valley Secondary Center" for the "Find in school name". A new page with the school information appeared. This school has reported data from over 15,000 atmosphere measurements!

They clicked on "graph" and then created a graph of the mean temperature, rain, and liquid water equivalent between Jan 1, 1999 and May 10, 1999.



1999	58.1500	24.9500	58.0	Kilingi-Nomme Gymnasium	19990427	BETULA
2000	58.1333	24.9333	58.0	Kilingi-Nomme Gymnasium	20000427	BETULA
2000	57.7883	-152.4030	35.0	Kodiak High School	20000430	ALNUS
2000	50.7667	7.7667	240.0	Kopernikus Gymnasium	20000410	BETULA
1999	57.9260	12.0843	15.0	Ledetskolan	19990426	BETULA
2001	57.9260	12.0843	15.0	Ledetskolan	20010502	BETULA
1999	60.6667	10.8000	230.0	Lena ungdomsskole	19990429	BETULA
2001	51.2700	6.3800	25.0	Lise Meitner Gesamtschule Koeln-Porz	20010331	BETULA
2001	51.3000	13.4100	130.0	Lise Meitner Gesamtschule Koeln-Porz	20010404	BETULA
2001	51.4200	6.5200	40.0	Lise Meitner Gesamtschule Koeln-Porz	20010329	BETULA
2001	51.5167	7.6833	115.0	Lise Meitner Gesamtschule Koeln-Porz	20010330	BETULA
2001	51.6760	7.1200	28.0	Lise Meitner Gesamtschule Koeln-Porz	20010331	BETULA
2001	50.8980	7.0633	51.0	Lise-Meitner Gesamtschule Koeln-Porz	20010312	BETULA
1999	41.4492	-75.6007	292.0	Mid Valley Secondary Center	19990507	BETULA
1999	41.4492	-75.6007	292.0	Mid Valley Secondary Center	19990507	QUERCUS
2000	41.4492	-75.6007	292.0	Mid Valley Secondary Center	20000507	BETULA
2000	41.4492	-75.6007	292.0	Mid Valley Secondary Center	20000507	QUERCUS
2001	41.4492	-75.6007	292.0	Mid Valley Secondary Center	20010503	BETULA
2001	41.4492	-75.6007	292.0	Mid Valley Secondary Center	20010503	QUERCUS
2000	36.9738	-120.0455	101.0	Millview Elementary School	20000316	POPULUS
2001	36.9738	-120.0455	101.0	Millview Elementary School	20010306	POPULUS
2000	63.8850	-152.3158	659.0	Minchumina Community School	20000522	BETULA
2000	63.8850	-152.3158	659.0	Minchumina Community School	20000524	BETULA
2000	63.8850	-152.3158	659.0	Minchumina Community School	20000527	BETULA
2000	63.8850	-152.3158	659.0	Minchumina Community School	20000527	POPULUS
2001	50.6062	12.1662	313.0	Mittelschule Elsterberg	20010331	BETULA
2001	50.6155	12.1723	360.0	Mittelschule Elsterberg	20010401	BETULA
2001	36.1303	-86.8367	227.0	Montgomery Bell Academy	20010406	QUERCUS
2001	36.1303	-86.8367	227.0	Montgomery Bell Academy	20010406	QUERCUS
2001	36.1318	-86.8365	220.0	Montgomery Bell Academy	20010407	QUERCUS
1999	58.2203	7.9250	16.0	Mosby skole (6-10 and 13-16)	19990414	BETULA
2000	36.1970	-92.2672	253.0	Norfork Elementary School	20000326	CARYA
2000	36.1972	-92.2688	253.0	Norfork Elementary School	20000315	ACER
2001	36.1970	-92.2672	253.0	Norfork Elementary School	20010405	CARYA
2001	36.1972	-92.2688	253.0	Norfork Elementary School	20010202	ACER



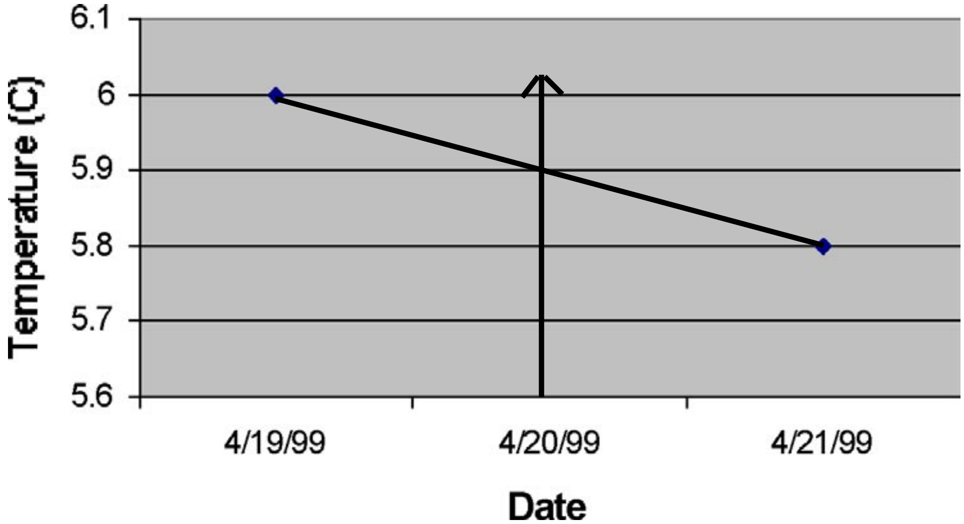
They then selected the “show table” option and a table with the data for the graph appeared at the bottom of the page and saved the file as a text file.

Next, they created a graph of temperature, rain and liquid water equivalent for snow between Jan. 1, 2000 and May 10, 2000; then a text file as they did for the 1999 data. They repeated these steps and created a text file for 2001 data.

The students opened a spreadsheet program on a computer and followed the instructions to open the 1999 text file.

In order to calculate Growing Degree Summation (GDS), they first examined the data to see if there were any missing days between Jan 1, 1999 and May 7, 1999 (the day of budburst). They found only one – April 20, 1999!! For that missing temperature date, they looked at the mean temperatures for the day before, April 19, and the day after, April 21. To estimate the mean temperature on April 20, they performed a linear interpolation, which is a technique often used by scientists to estimate the values of missing data. The graph below shows the mean temperature data for April 19 (6.0 C) and April 21 (5.8 C). They drew a line connecting these two points and then estimated the mean temperature for April 20 as 5.9 C.

They next calculated the GDS for 1999 for the two tree species observed by the students at Mid Valley Secondary Center. Both tree species had a budburst date of May 7. They started with January 1 and added all the temperature values greater than 0.0 C up to the day of budburst. They ignored the temperatures less than 0.0 C, as stated in the *What do scientists look for in the data?* section. They calculated a GDS of 619.1C. The table below shows their results.



Date	Mean Temperature	GDS
1/1/1999	-11.5	0
1/2/1999	-13	0
1/3/1999	-4.2	0
1/4/1999	-3.5	0
1/5/1999	-10.5	0
1/6/1999	-11	0
1/7/1999	-7.5	0
1/8/1999	-9.8	0
1/9/1999	-2.5	0
1/10/1999	-6	0
1/11/1999	-8.5	0
1/12/1999	-7	0
1/13/1999	-1	0
1/14/1999	-7.8	0
1/15/1999	-7	0
1/16/1999	-6	0
1/17/1999	2	2
1/18/1999	4	6
1/19/1999	6	12
1/20/1999	0	12
1/21/1999	2	14
1/22/1999	2.5	16.5
1/23/1999	7	23.5
1/24/1999	11.5	35
1/25/1999	4.5	39.5
1/26/1999	-1	39.5
1/27/1999	-1.5	39.5
1/28/1999	3.5	43
1/29/1999	2	45
1/30/1999	-4.5	45
1/31/1999	-8	45
2/1/1999	1	46
2/2/1999	4	50
2/3/1999	7.5	57.5
2/4/1999	4.5	62
2/5/1999	2	64
2/6/1999	-1.2	64
2/7/1999	1	65
2/8/1999	-0.5	65
2/9/1999	-3	65
2/10/1999	3.5	68.5
2/11/1999	3	71.5

Date	Mean Temperature	GDS
2/12/1999	9	80.5
2/13/1999	4	84.5
2/14/1999	-7	84.5
2/15/1999	-5.5	84.5
2/16/1999	2	86.5
2/17/1999	9	95.5
2/18/1999	3.5	99
2/19/1999	1.5	105.5
2/20/1999	2.5	108
2/21/1999	-3.2	108
2/22/1999	-10.5	108
2/23/1999	-11.5	108
2/24/1999	-3	108
2/25/1999	-2	108
2/26/1999	0	108
2/27/1999	0	108
2/28/1999	3.8	111.8
3/1/1999	2.5	114.3
3/2/1999	1	115.3
3/3/1999	3	118.3
3/4/1999	2.5	120.8
3/5/1999	-2.5	120.8
3/6/1999	0.5	121.3
3/7/1999	-4.5	121.3
3/8/1999	-10	121.3
3/9/1999	-8	121.3
3/10/1999	-4.5	121.3
3/11/1999	-1.5	121.3
3/12/1999	-3.5	121.3
3/13/1999	-3	121.3
3/14/1999	0.5	121.8
3/15/1999	3	124.8
3/16/1999	1	125.8
3/17/1999	7.5	133.3
3/18/1999	13.5	146.8
3/19/1999	5.5	152.3
3/20/1999	1.5	153.8
3/21/1999	3	156.8
3/22/1999	3	159.8
3/23/1999	2	161.8
3/24/1999	3.5	165.3
3/25/1999	6	171.3

Date	Mean Temperature	GDS
3/26/1999	-1	171.3
3/27/1999	3.5	174.8
3/28/1999	9.2	184
3/29/1999	10	194
3/30/1999	12	206
3/31/1999	10	216
4/1/1999	13.8	229.8
4/2/1999	14.5	244.3
4/3/1999	14.5	258.8
4/4/1999	16	274.8
4/5/1999	5	279.8
4/6/1999	9	288.8
4/7/1999	14	302.8
4/8/1999	15	317.8
4/9/1999	15	332.8
4/10/1999	9	341.8
4/11/1999	5	346.8
4/12/1999	4	350.8
4/13/1999	5.5	356.3
4/14/1999	8	364.3
4/15/1999	8	372.3
4/16/1999	13	385.3
4/17/1999	6	391.3
4/18/1999	8.5	399.8
4/19/1999	6	405.8
4/20/1999	est 5.9	411.7
4/21/1999	5.8	417.5
4/22/1999	10	427.5
4/23/1999	13.2	440.7
4/24/1999	3.5	444.2
4/25/1999	4.8	449
4/26/1999	10.5	459.5
4/27/1999	11.5	471
4/28/1999	11.1	482.1
4/29/1999	10.8	492.9
4/30/1999	12.5	505.4
5/1/1999	13.5	518.9
5/2/1999	14.2	533.1
5/3/1999	16.5	549.6
5/4/1999	15	564.6
5/5/1999	17.5	582.1
5/6/1999	18.5	600.6
5/7/1999	18.5	619.1

They then calculated the GDS for 2000 and 2001 following the steps described above. Both species of trees, *Betula populifolia* and *Quercus alba,* had the same date of budburst for each year. If the dates differed within the same year they would have had to calculate the GDS for each tree species. Here are their results:

Mid Valley Secondary Center -
Betula populifolia *and* Quercus alba

Year	**1999**	**2000**	**2001**
Budburst	May 7	May 7	May 3
GDS	619.1	734.4	493.4

It seems that the budburst dates are nearly the same for all three years but that the GDS values vary greatly. In fact the year with the earlier budburst date (May 3) had the lowest GDS of 493.4C. This is the opposite of what they predicted– a warmer spring, then an earlier budburst.

Next, the students looked at moisture availability – the difference of inputs and outputs of water available to the soil. Maybe that influenced when budburst occurred. They summed the precipitation data for the 29 days before budburst and the day of budburst (a total of 30 days). This includes both the rain and liquid water equivalent of melted snow. For rain, there was a total of 49.5 mm for the 30 days, although one day was missing (April 20). Rain could have fallen on that day. They checked to see if there were any liquid equivalent of new snow measurements. No snow fell during that time period.

Date	**Rain**	**Days**	**Equiv**	**Days**
19990408	0	1	0	1
19990409	6.8	1	0	1
19990410	6.6	1	0	1
19990411	0	1	0	1
19990412	11.8	1	0	1
19990413	0	1	0	1
19990414	0	1	0	1
19990415	0	1	0	1
19990416	0.1	1	0	1
19990417	4.2	1	0	1
19990418	0	1	0	1
19990419	0.1	1	0	1
missing				
19990421	0.7	1	0	1
19990422	0	1	0	1
19990423	4.3	1	0	1
19990424	11	1	0	1
19990425	0	1	0	1
19990426	0	1	0	1
19990427	0	1	0	1
19990428	0	1	0	1
19990429	0	1	0	1
19990430	0	1	0	1
19990501	0	1	0	1
19990502	0	1	0	1
19990503	0.1	1	0	1
19990504	1.4	1	0	1
19990505	2.4	1	0	1
19990506	0	1	0	1
19990507	0	1	0	1
Total	**49.5**			

Next, they calculated the outputs from evaporation and transpiration. The output values for each day in the 30 days was determined from a potential evapotranspiration (PET) table given in the What do scientists look for in the data? section. To find the PET value for each day, they looked at the average temperature value and found the corresponding PET value. If the temperature value for a given day fell between values listed in the table, they did a linear interpolation. The PET values for 30 days were added, shown below.

Date	Average Temperature	PET
4/8/99	15	2.1
4/9/99	15	2.1
4/10/99	9	1.5
4/11/99	5	1.1
4/12/99	4	1.1
4/13/99	5.5	1.15
4/14/99	8	1.4
4/15/99	8	1.4
4/16/99	13	1.9
4/17/99	6	1.2
4/18/99	8.5	1.45
4/19/99	6	1.2
4/20/99	est 5.9	1.2
4/21/99	5.8	1.2
4/22/99	10	1.6
4/23/99	13.2	1.9
4/24/99	3.5	1.05
4/25/99	4.8	1.1
4/26/99	10.5	1.65
4/27/99	11.5	1.75
4/28/99	11.1	1.7
4/29/99	10.8	1.7
4/30/99	12.5	1.85
5/1/99	13.5	1.95
5/2/99	14.2	2
5/3/99	16.5	2.35
5/4/99	15	2.1
5/5/99	17.5	2.45
5/6/99	18.5	2.6
5/7/99	18.5	2.6
Total		**50.35**

Next, they subtracted the outputs from the inputs for each year to see if there were moisture excesses or deficits. Negative difference values indicate a decrease in water, in other words, drying conditions. Positive difference values indicate an increase in water.

Year	1999	2000	2001
Total precipitation	49.5 mm	56.1 mm	37.4 mm
PET	50.35 mm	54 mm	56.35 mm
Difference (moisture availability)	-0.85 mm	2.1 mm	-18.95 mm

During the spring of 2001 there was a major decrease in the available moisture: –18.95 mm. The other two years moisture conditions remained steady. They then compared the moisture availability values with the budburst dates and GDS values in a table shown above.

Year	1999	2000	2001
Budburst	May 7	May 7	May 3
GDS	619.1	734.4	493.4

This is totally different than what they expected! Budburst occurred earlier in drier, colder conditions. They were not sure what to conclude. Perhaps for these species, the amount of daylight is more important than both moisture availability and temperature. They were curious to see if the same pattern resulted in 2002 and wanted to look at the data from another school to see if the same pattern is found. As well, they decided to go to the library and find out more about the tree species.

Green-Up Protocol

Purpose

To observe plant green-up and report data that will be used by scientists to validate satellite estimates of the beginning of the plant growing season

Overview

Students monitor budburst and growth of leaves of selected trees, shrubs, or grasses. Species chosen should be native, deciduous, and dominant in your area.

Student Outcomes

Students will learn to,

- observe when buds burst open at the beginning of the growing season;
- observe how leaves grow to maturity;
- identify tree species native to your area;
- examine relationships among budburst, leaf growth and climate factors;
- predict the timing of budburst for upcoming seasons;
- compare the rate of leaf growth of different plant species;
- communicate project results with other GLOBE schools;
- collaborate with other GLOBE schools (within your country or other countries); and
- share observations by submitting data to the GLOBE archive.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is a major source of energy at the Earth's surface.

Life Sciences

Organisms have basic needs.

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Earth has many different environments that support different combinations of organisms.

Plants and animals have life cycles.

Energy for life derives mainly from the Sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Estimating dominant plant species

Identifying plant species (advanced level)

Observing leaf growth

Making leaf measurements

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

Field time: 20 minutes excluding travel time.

Level

All

Frequency

At least twice a week beginning two weeks prior to the anticipated start of green-up, if possible

Materials and Tools

Green-Up Data Sheet

Grass Green-Up Field Guide and/or *Tree and Shrub Green-Up Field Guide*

Tree and Shrub Green-Up and Green-Down Site Selection Field Guide and/or *Grass Green-Up and Green-Down Site Selection Field Guide*

Green-Up and Green-Down Site Definition Sheet

Ruler with mm marks

Flagging tape, 1 label per student

Pencil or pen

Dichotomous keys and/or other local species guides

Compass

Camera

Calculators (optional)

Preparation

Review dominant plant species of school's GLOBE Study Site.

Prerequisites

Knowledge of common plant species at the site

Green-Up Cards Learning Activity (suggested)

Budburst Sneak Preview Learning Activity (suggested)

Green-Up and Green-Down Site Selection

Before selecting your Green-up site, here are some things to consider. Green-down site selection has the same considerations.

1. Your plant phenology site should be in an area where green-up and green-down of native plants is due to climatic factors such as increased temperature or precipitation. Watering and fertilization alter plants' green-up and green-down cycles, and the data would not be representative of natural vegetation and local climate connections. Buildings absorb solar radiation and shelter sites from wind. Therefore, avoid sites near buildings or where watering or fertilization is done. For the phenology protocols, near means that the plant is closer to a building than the height of the building. To determine if the plant is too close to a building, stand at the plant and sight the top of the building through your clinometer. If the angle is greater than 45˚, the building is too close.
2. Non-native species, called exotics, have green-up and green-down cycles that may not be tied to the local climate. Often this is because exotics have not evolved to survive in the local climate. If you are unsure which plants are natives or have evolved to grow in a climate regime similar to yours, ask a local greenhouse or agricultural extension agent, or the appropriate staff at a local college or university.
3. Your green-up and green-down site must be accessible so that students can visit the site at least twice a week. It may be the same as a Land Cover Sample Site or your Atmosphere Study Site. Be sure to determine the location of your site by identifying the latitude, longitude and elevation following the *GPS Protocol*.
4. Because the results of your green-up and green-down measurements may be related to temperature and precipitation data from the *Atmosphere Investigation* and soil moisture and temperature data from the *Soil Investigation*, it is better to choose a site close to the Atmosphere and Soil Moisture Study Sites. The local topography can cause weather to vary even within short distances. This is particularly true in mountainous and coastal regions. The horizontal distance between the Phenology and Atmosphere and Soil Moisture Sites should be less than 2 kilometers and the elevation differences less than 100 meters, so that you can see whether your atmosphere data correlates with your green-up and green-down data.
5. Green-up and green-down detected by satellites are influenced mostly by a few dominant overstory plant species. These will be the species with the largest share of canopy coverage. If you are using a Land Cover Sample Site, you already know the dominant species. If you are using a different site, use the one to three over-story species that are dominant for your region. These over-story plants may be coniferous trees, broadleaf trees, broadleaf shrubs, or grasses. For phenology measurements you should choose a deciduous plant so, if the dominant plant species are all evergreen conifers, use the under-story broadleaf shrubs as your green-up plants. For example, if your study site is 90 percent white pine (a coniferous tree) and 10 percent sugar maple (a broad leaf tree), use the sugar maple trees as the study plants.
6. Scientifically, it is most useful if the tree or shrub branch used for the *Green-Up Protocol* is the same as the one used for the *Green-Down Protocol*. However, you may do only the Green-Up or Green-Down measurements or you may use different branches or even different sites if this is necessary to match your educational requirements. If you use different sites for green-up and green-down, create a site definition for each.
7. Since a change in plant growing season may be due to a change in climate, students at your school should try to use the same site, the same plant species, and the same part of the plant consistently, year after year.

Tree and Shrub Green-Up and Green-Down Site Selection

Field Guide

Task

Define the site for green-up and green-down measurement of trees and shrubs.

What You Need

- ❑ *Green-Up and Green-Down Site Definition Sheet*
- ❑ *GPS Data Sheet*
- ❑ *GPS Protocol Field Guide*
- ❑ Flagging tape or other durable identification
- ❑ Dichotomous keys and/or other local species guides
- ❑ GPS receiver
- ❑ Compass
- ❑ Pencil or pen

In the Field

1. Complete the top of the *Green-Up and Green-Down Site Definition Sheet*.

2. Select one tree or shrub. The tree or shrub should be among the dominant native species in your area, deciduous, and easily accessible.

3. Select a healthy and relatively large branch on the south side of the plant in the Northern Hemisphere or the north side of the plant in the Southern Hemisphere. Use a compass or GPS receiver to determine direction. If a lower branch is chosen, it should be on the edge of the stand of trees or shrubs since branches inside a stand may experience a different microclimate due to shading.

4. Identify genus and species using field guides or the help of plant specialists. Record the genus and species on the *Green-Up and Green-Down Site Definition Sheet*.

5. Mark the branch with flagging tape or some other durable identification. Label the flagging tape with a unique number and your name/group name, school name and class.

6. Take a GPS measurement following the *GPS Protocol*.

Grass Green-Up and Green-Down Site Selection

Field Guide

Task

Define the site for green-up and green-down measurement of grasses.

What You Need

- ❑ *Green-Up and Green-Down Site Definition Sheet*
- ❑ *GPS Data Sheet*
- ❑ *GPS Protocol Field Guide*
- ❑ GPS receiver
- ❑ Pencil or pen
- ❑ Nails or stakes or other durable identifiers
- ❑ Meter stick or tape measure
- ❑ Dichotomous keys and/or other local species guides

In the Field

1. Complete the top of the *Green-Up and Green-Down Site Definition Sheet*.
2. Identify genus using field guides or help of plant specialists. Record the genus on the *Green-Up and Green-Down Site Definition Sheet*.
3. Select a one-meter square area dominated by grass plants. Mark your one-meter square plot with nails or stakes or other durable identifiers.
4. Take a GPS measurement following the *GPS Protocol*.

Teacher Support

Advance Preparation

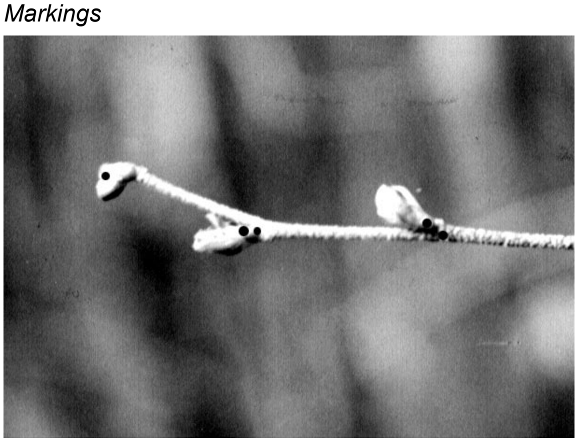
Students should complete the *Green-Up Cards* and *Sneak Preview of Budburst* learning activities prior to budburst and green-up.

Check with local sources for average green-up dates to help determine when to start observations. In areas where snow is common, observations should begin immediately after snow melt. For each visit where no green-up was observed for the study plant, students should fill in the observation date in the *Pre-Green-Up Section* of the *Green-Up Data Sheet*.

Frequency of Observations

Ideally, each student should visit his/her plant at least two times a week to check for the start of green-up and continue observing until leaf growth plateaus. For trees or shrubs, the start of green-up occurs when one of the four sample buds (selected for observation) swells and you can see tiny green leaves starting from the bud. Some of the buds on your branch may not green-up on exactly the same day. For grasses, the start of green-up occurs when any initial green grass shoot is first observed. See the *Green-Up Cards* learning activity for pictures of grass shoot initiation.

Figure EA-GU-1: Sample Buds Marked with Permanent Markings



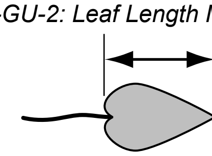
For most areas of the world, there is only one green-up and green-down cycle. However, there are places where multiple wet and dry seasons can occur in a single year, resulting in multiple green-up and green-down cycles. Because of this possibility, we are asking you to report which cycle you are observing. If there is only one cycle, then you report green-up cycle 1. The onset of the first green-up after 1 January is considered green-up cycle 1.

Sometimes green-up can last past the end of the school year. To be scientifically useful, measurements should be taken of the leaf until it reaches maturity. Enlisting the help of parents or other members of the community may encourage and support the students to continue taking the measurements after the school year ends.

Measurement Procedure

For green-up observations, it is important to measure leaf length is from the leaf base to the leaf tip. Do not include the leaf stem or petiole as part of the leaf length measurement.

Figure EA-GU-2: Leaf Length Measured without



There are two *Data Sheets* for green-up; one for grasses, the other for trees and shrubs. *For each tree and shrub leaf*, here are the categories for the state of leaf from dormancy to maturity. Students report one of these for each observation.

- Report "dormant" if the bud is unchanged and still in its dormant state during cold or dry seasons.
- Report "swelling" if the bud is getting bigger.
- Report "budburst" when the bud first opens and the green tips of leaves can be seen.
- After budburst, students measure the length of each leaf and report the length in millimeters.
- Report "lost" if the leaf gets lost for some reason.

For grasses, here are the options for state of leaf.

- Report "no shoot" before the leaves of grass can be seen.
- Measure the length in millimeters after the shoot appears.
- Report "lost" if something happens to the marked leaves.

The following page shows examples of completed *Tree and Shrub Green-up Data Sheet* and a *Grass Green-up Data Sheet* you can show your students.

Questions for Further Investigation

Is there a relationship between air temperature and budburst dates reported for the GLOBE schools in your region?

How does plant green-up affect soil water?

What other animals (butterflies, waterfowl, songbirds) arrive after plants green-up, when, and why?

Does the timing of green-up occur earlier or later at higher elevations in your region? Why?

Does the timing of green-up occur earlier or later inland or near the coast in your region? Why?

Example of Completed Data Sheets

Tree and Shrub Green-Up

Date (day and month)	**Leaf 1** (Dormant, Swelling Budburst, Length (mm), Lost)	**Leaf 2** (Dormant, Swelling Budburst, Length (mm), Lost)	**Leaf 3** (Dormant, Swelling, Budburst, Length (mm), Lost)	**Leaf 4** (Dormant,Swelling, Budburst, Length (mm), Lost)	**Reported to GLOBE**
3 March	*dormant*	*dormant*	*dormant*	*dormant*	☑
6 March	*dormant*	*dormant*	*dormant*	*dormant*	☑
11 March	*swelling*	*swelling*	*swelling*	*dormant*	☑
14 March	*budburst*	*budburst*	*swelling*	*Swelling*	☑
18 March	*2*	*4*	*budburst*	*Budburst*	☑
22 March	*6*	*10*	*5*	*6*	❑
25 March	*12*	*15*	*10*	*12*	❑
29 March	*20*	*22*	*18*	*19*	❑
2 April	*30*	*32*	*25*	*28*	❑
5 April	*38*	*lost*	*36*	*38*	❑
8 April	*45*		*42*	*44*	❑
11 April	*45*		*44*	*44*	❑
14 April	*45*		*44*	*44*	❑
					❑

Grass Green-Up

Date (day and month)	**Leaf 1** (No shoot, length (mm), or lost)	**Leaf 2** (No shoot, length (mm), or lost)	**Leaf 3** (No shoot, length (mm), or lost)	**Leaf 4** (No shoot, length (mm), or lost)	**Reported to GLOBE**
10 April	*No shoot*	*No shoot*	*No shoot*	*No shoot*	☑
13 April	*2*	*3*	*No shoot*	*No shoot*	☑
17 April	*8*	*10*	*5*	*6*	☑
20 April	*18*	*20*	*15*	*18*	☑
24 April	*29*	*27*	*lost*	*30*	❑
27 April	*36*	*35*		*40*	❑
1 May	*48*	*50*		*55*	❑
4 May	*58*	*50*		*55*	❑
8 May	*58*	*50*		*55*	❑
					❑
					❑
					❑

Tree and Shrub Green-Up Protocol

Field Guide

Task

Observe and record green-up in trees and shrubs.

What you Need

First visit only

- ❑ *Green-Up Data Sheet*
- ❑ Pencil or pen
- ❑ Ruler with mm units
- ❑ Fine-tip permanent marker
- ❑ Camera
- ❑ Compass

Every visit

- ❑ *Green-Up Data Sheet*
- ❑ Pencil or pen
- ❑ Ruler with mm units

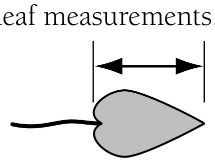
In the Field

First time only/getting started

1. Complete the upper portion of your data sheet.
2. For the selected tree or shrub, locate the bud at the end of the branch. Label this bud by marking one dot on the branch next to the bud.
3. Locate the three other buds closest to this bud. Label these buds by marking two, three, or four dots next to them.
4. Take a photograph from the center of your site looking in the north, south, east, and west directions.

Every visit

1. Examine each bud.
   - Record “dormant” if the bud is unchanged.
   - Record “swelling” if the bud is getting bigger.
   - Record “budburst” the first day you see the green tips of leaves.
   - Record “lost” if something happens to the bud and you cannot continue observations.
2. After each budburst, use a ruler to measure the length of the leaf or leaves. Do not include leaf stem or petiole in your leaf measurements.



3. Measure the leaves until the leaf length stops increasing. Different leaves may stop growing at different dates.

Grass Green-Up Protocol
Field Guide

Task
Observe and record plant green-up in grasses.

What You Need

First visit only

- ❑ *Green-Up Data Sheet*
- ❑ Pencil or pen
- ❑ Fine-Tip Permanent Marker
- ❑ Ruler with mm units
- ❑ Camera
- ❑ Compass

Every visit

- ❑ *Green-Up Data Sheet*
- ❑ Pencil or pen
- ❑ Ruler with mm units
- ❑ Fine-Tip Permanent Marker (until four new grass shoots have been marked)

In the Field

First time only/getting started

1. Complete the upper portion of your *Data Sheet.*
2. Before new grass shoots emerge, take a photograph in the north, south, east, and west directions.

Every visit

1. Look for new green grass shoots.
2. Mark the base of the first grass shoot with a single dot.
3. Mark the second shoot with two dots, the third with three dots and the fourth shoot with four dots.
4. Use the ruler to measure the length of the shoots to the nearest millimeter.
5. Measure the leaves until the leaf length stops increasing.

Frequently Asked Questions

1. Will the marker hurt the bud?
Do not mark the bud itself. Mark the woody branch next to it. That way you will not hurt the plant.

2. What do you mean by a relatively large branch?
Use your judgement. Each branch should be healthy and large relative to the other branches on the tree or shrub. You want the branch to still be there next year. Be careful not to damage the branch during the labeling and measurements.

3. What if a branch breaks during the study?
Continue your observations by teaming up with other students and observing their branch.

4. Will all the buds start to swell at the same time?
No. Some of the buds on your branch may not green-up on exactly the same day as the terminal bud.

5. Should I look at the same buds from year to year?
You should observe the same branch, which will typically have new terminal buds each year.

6. What if needle-leaved trees are the abundant vegetation?
Usually there are understory deciduous shrubs that can be used instead. For example, Snowberry in Douglas Fir, Gamel Oak in Ponderosa Pine. Typically these deciduous plants are what the satellites are detecting as Green-up. The Green-up of conifers is a subtle process and not easily observed.

7. What if multiple leaves emerge from a single bud after the bud bursts open?
Choose one of the leaves and mark it with the permanent marker. Take measurements of the marked leaf.

8. How do I mark the grass shoots if they start on the same day?
Mark the base of the four longest grass shoots that appear at the earliest date.

9. What do I do if on the first day I see shoots, I see more than four? How do I select the shoots to study?
Mark the base of the four longest grass shoots that appear on the first day.

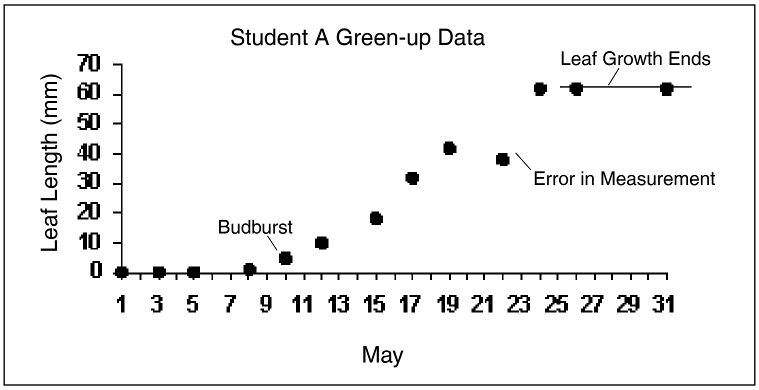
10. How long will it take for a leaf to mature?
That depends. It may take a week in Alaska with 18 hours of sunlight during green-up. In other locations it may take a month or more.

11. What if there are grass shoots the first day when I go to take a picture of the site?
Mark the base of the four longest grass shoots that are present on this day.

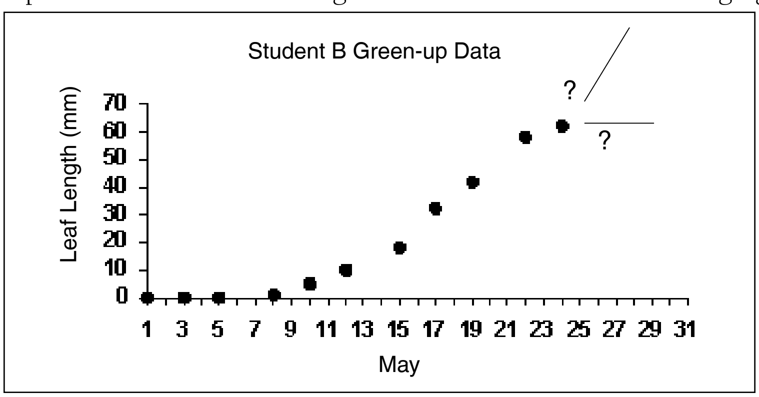
Plant Phenology: Green-up – Looking At the Data

Are the data reasonable?

The first step in looking at plant phenology data is to see if the data seem reasonable and make sense. Is the green-up leaf length always greater than or equal to previous measurements? Looking at a graph of green-up data, such as shown in Figure 1, makes it easy to check. Notice from the following figure that leaf length on May 22 is less than May 19. Either the leaf measurement on May 19 or May 22 is probably an error.

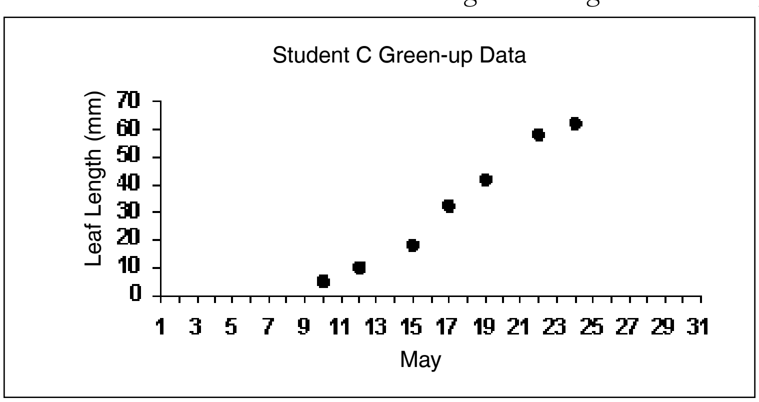


Another potential problem is illustrated using Student B's data in the following figure.



Notice that there are not enough measurements showing that leaf growth stopped. Has leaf growth reached 100 percent by May 24, or will it continue for weeks? It is impossible to tell unless there at least 3 measurements showing that leaf length has reached a constant.

Student C's data have 2 problems: 1) it is impossible to estimate when budburst occurred because the student did not record at least 3 dates prior to budburst. 2) it is impossible to estimate percent of leaf growth from the data since there are not at least 3 measurements showing that leaf growth has stopped at the end of May.



What do scientists look for in the data?

Scientists are very interested in when leaves appear in spring and how quickly they expand. The timing and rate of fall leaf changes, such as color changes and leaf drop, are also important. It may seem strange that such easy to observe and common events are important for Earth System Science, but they are.

For example, many scientists use data from a NASA sensor, the Moderate Resolution Imaging Spectroradiometer (MODIS), to monitor the seasonal dynamics of leaves. Green-up/green-down data gathered by GLOBE students, using consistent methods all over the world, are one of the best tools with which to verify the accuracy of these satellite products.

Computer models are one of the main research tools used by scientists to predict the future climate of the planet. Seasonal vegetation activity is an important component of this research. Many models contain programs that are used to predict the expansion of plant leaf material. Without data against which to compare these models, we cannot believe the model predictions. By using GLOBE green-up/green-down data to help develop these models, scientists will be able to better predict our future climate.

Some applications of GLOBE data can be very specific, in particular when plant phenology is linked to other events. Many plant pests like gypsy moths appear during certain leaf developmental stages. By linking GLOBE green-up data with the appearance of gypsy moths, scientists are working to develop better pest treatment approaches.

In short, by participating in the GLOBE *Green-Up/Green-Down Protocols,* you will be helping to gather data that scientists will use in many fields Earth System Science, sometimes in unpredictable ways!

An Example of Student Research

In a science class, a teacher introduced the topic of phenology. No one in the class had heard of the word “phenology”, much less knew what it meant. So she explained what phenology meant and asked students for examples of seasonal change. The school year started a little over a month ago, and the class discussed some observations they noticed about fall. One student noticed that the air temperature was getting colder so they were putting on thicker sweaters and jackets to keep warm. Another remarked that it was starting to get dark when they were walking home after school. A third student mentioned that the leaves on the trees were changing color and that some trees turned red while others turned yellow or brown. Another student mentioned that many local farmers had food stands selling their fruits and vegetables.

As an assignment, the teacher asked the students to think of more examples. She encouraged them to ask their parents, grandparents and others in their community for examples as well.

After the students became comfortable with the concept of phenology and specific examples for their area, the teacher introduced the students to the GLOBE *Green-up Protocol* and told the students that they would be doing the *Green-up Protocol* next spring. They were instructed to design one or more research projects to do next spring. The teacher encouraged them to look at the student data on the GLOBE Web site to get some ideas.

The students were somewhat familiar with the GLOBE maps and graphs and realized that sites are defined for all the data students collect. So, they wanted to see if there were any nifty maps or graphs for phenology sites. After clicking on *Maps and Graphs* on the navigation bar, they clicked on *GLOBE Sites* and then, *Green-up/Green-down Site Visualization. The* new page listed phenology sites organized by country. GLOBE schools at many countries are collecting green-up and green-down data! They scrolled through the list of countries and schools and decided to look at Osaka Prefectural Higashisumiyoshi Technical High School in Japan. Students at this school have 9 phenology sites with lots of data at each site!

After they clicked on a phenology site, a graph and a table of data would show for that site. After looking at the data for each site, they discovered that students at Osaka Prefectural Higashisumiyoshi Technical High School are observing green-up and green-down for three different tree species – *Liquidambar styraciflua, Cornus florida*, and *Acer palmatum*.

They were curious to see if there were any patterns or differences in the green-up data for the different species. Graphs for the different tree species are shown in Figures EA-GU-3, EA-GU-4 and EA-GU-5. Figure EA-GU-3 shows data for *Liquidambar styraciflua* at site 1 (GRN-01); Figure EA-GU-4 shows data for *Cornus florida* at site 2 (GRN-02); Figure EA-GU-5 shows data for *Acer palmatum* at site 3 (GRN-03). Looking at the graphs the students made a number of observations:

1. Budburst for all the leaves for all three species occurred about the same time.
2. There was a longer time that the buds showed swelling for the tree, *Liquidambar styraciflua*, at site GRN-01 (Figure EA-GU-3).
3. The final lengths of the leaves for *Liquidambar styraciflua* (Figure EA-GU-3) and *Acer palmatum* (Figure EA-GU-5) were about the same, but the maximum leaf length for *Cornus florida* (Figure EA-GU-4) was much longer (almost twice the length of the other tree species).
4. *Liquidambar styraciflua* and *Acer palmatum* reached the maximum length earlier than *Cornus florida.*
5. One of the leaves for *Liquidambar styraciflua* fell off at site 1. That was curious and they wanted to know if there were any comments to explain why the leaf fell off. They looked at the comments section in the table of data and unfortunately there were no comments.

They decided to download the data from the GLOBE data archive and put the data into a spreadsheet program. To do this, they went to the table of data for each site and followed the instructions to download the data as a text file. They had three files, one for each site (GRN-01, GRN-02, and GRN-03).

Next, the students followed the instructions for the spreadsheet program to open a text file. When opening up the data, they followed the instructions so that the column for dates was recognized as dates (year, month and day) and not large numbers.

The column for LI (Leaf ID) has four values (1, 2, 3, and 4) – a number for each leaf that was measured. When they looked at the data in the spreadsheet, the data were ordered by date. They were interested to create graphs for each leaf like that shown on the GLOBE web site (see Figures EA-GU-3, EA-GU-4, and EA-GU-5). So, they used the spreadsheet tool to sort the columns of data by the Leaf ID. This then allowed them to graph each leaf more easily.

They organized the data for each site (GRN-01, GRN-02, and GRN-03) by the Leaf ID. One student suggested that they look at green-up data for each species on the same graph. This was easy to do since the data were now organized by Leaf ID. They created a new spreadsheet with data from each site. To do this, they copied and pasted the data from the original files. The compiled data from the three sites are shown in Table EA-GU-1.

Next, they made a graph of the data comparing the leaf lengths of the three species, shown in Figure EA-GU-6. For each species, they graphed one of the four leaves just to see how the data compared. It was interesting to see the data on the same graph and in more detail than what the GLOBE web site offered. From the GLOBE graph it looked as if all three species had budburst around the same date, but this graph shows that budburst for *Liquidambar styraciflua* occurred later. They also noticed that the leaves grew at about the same rate. In other words, after the buds burst open, the amount the leaves grew each week was about the same. However, since the final length of *Cornus florida* is much longer, it took longer to reach the length of a mature leaf.

They were very excited about this observation. Is this typical? In the same location, do leaves on different plants in the same area grow similarly? They decided that this was a good research question to ask for next spring. They decided to find out what are some native tree species in the area and select three like the school in Osaka, Japan, and compare the way the leaves grow. They predicted that the tree species with longer leaf lengths at maturity will take longer to reach the length at maturity.

In addition, they wanted to look at other GLOBE school data and see how fast leaves grow in the spring in different climates. Does the length of the growing season affect how fast leaves grow? After exploring the GLOBE data archive, they may have other research questions they want to ask for their research next spring.

Figure EA-GU-3

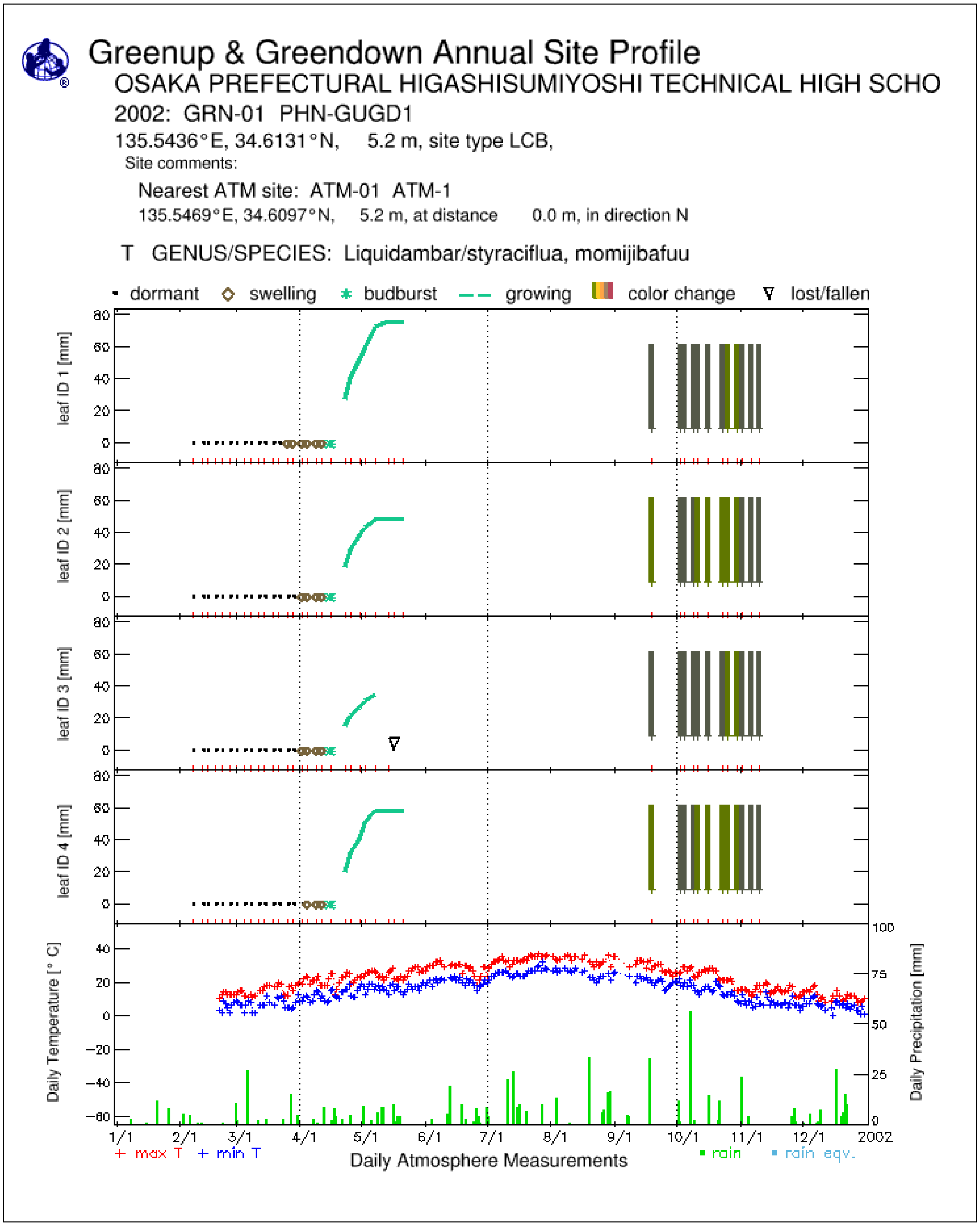


Figure EA-GU-4

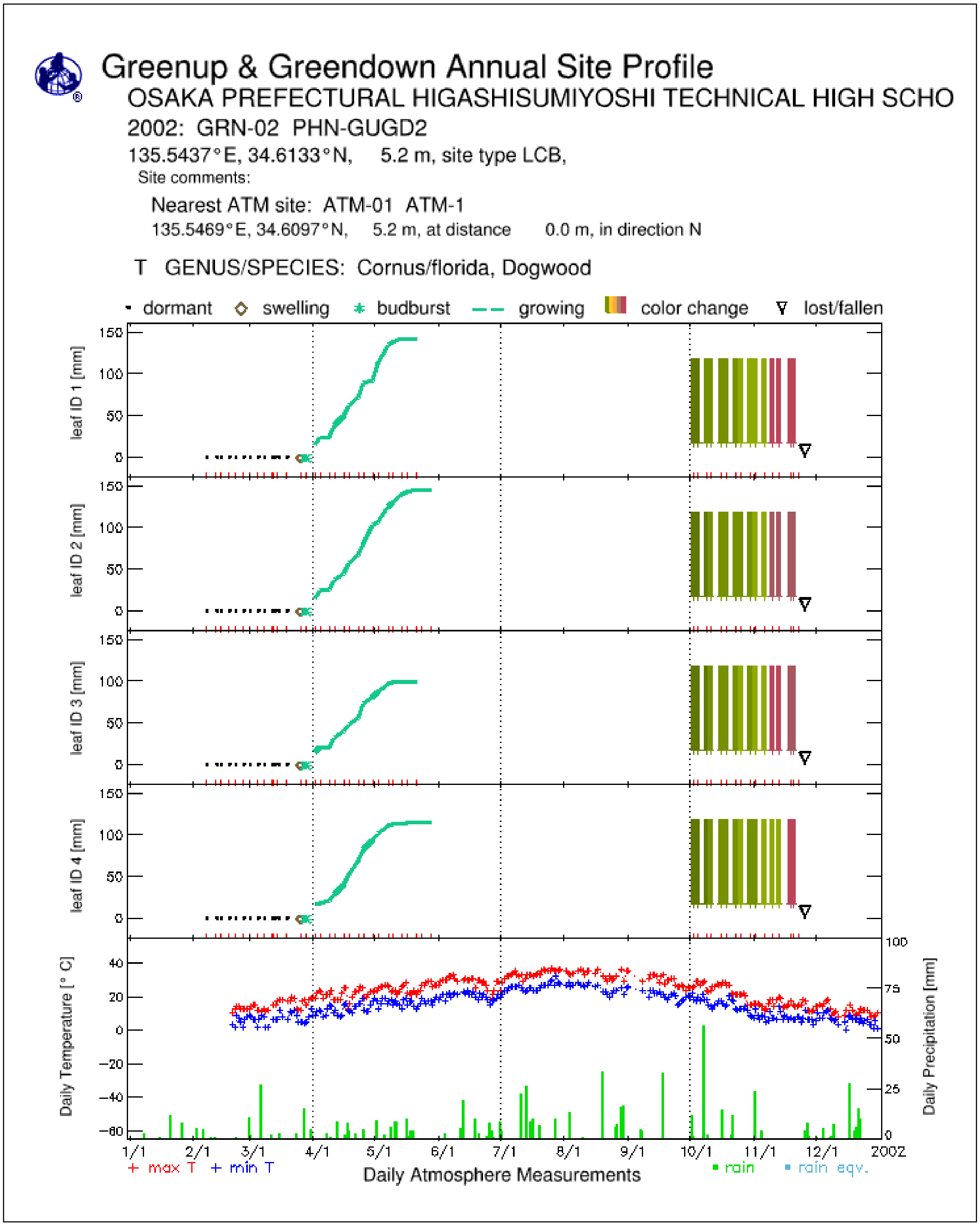


Figure EA-GU-5

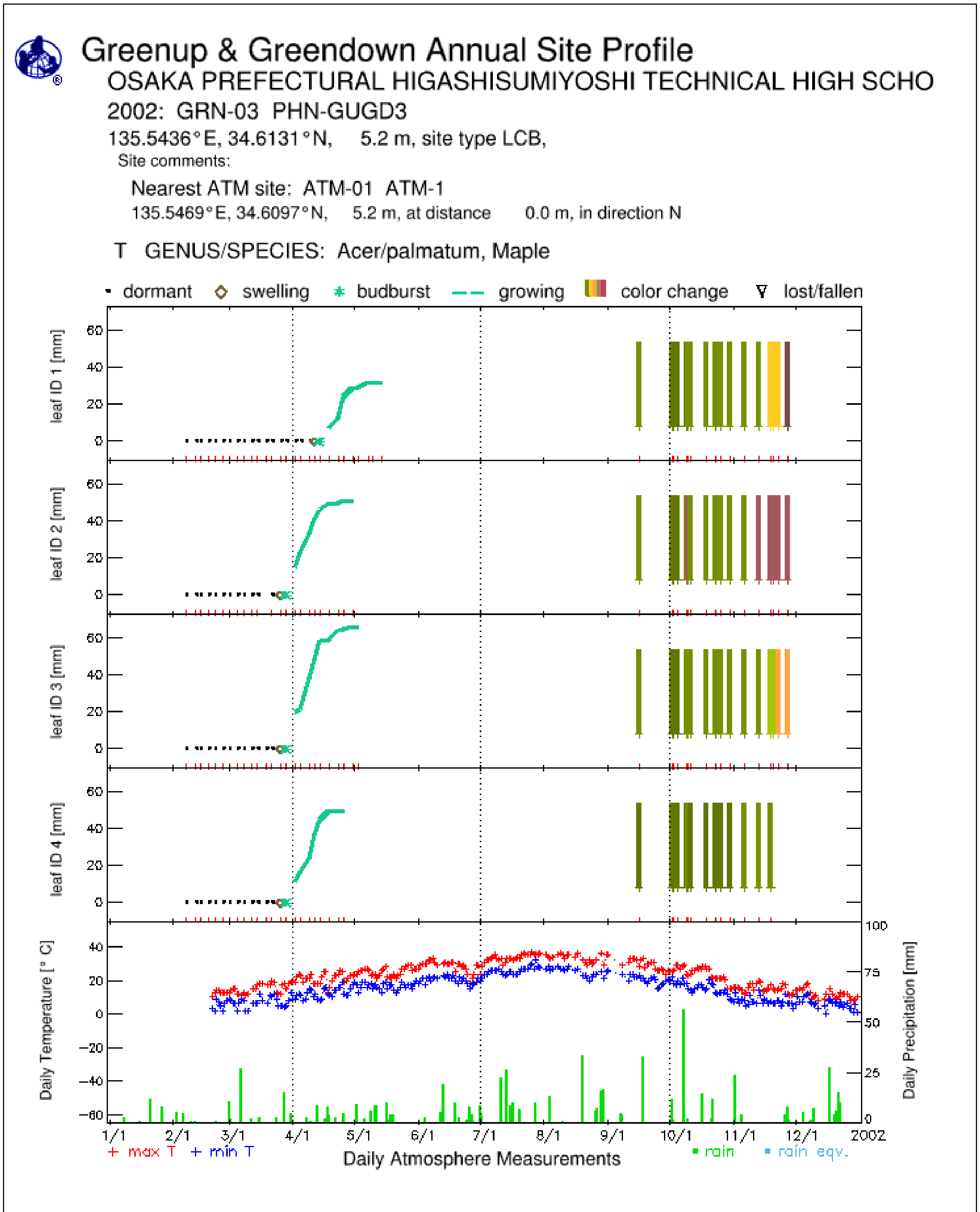
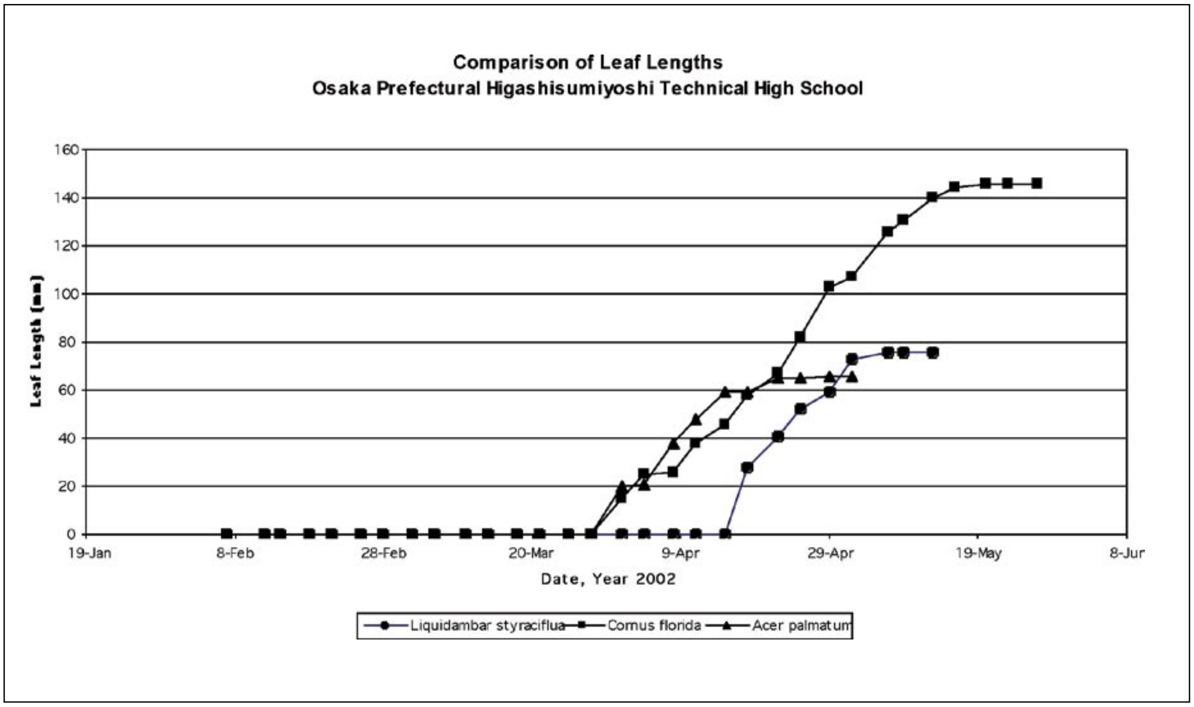


Table EA-GU-1

Date	GRN-01	GRN-02	GRN-03
	Liquidambar styraciflua	**Cornus florida**	**Acer palmatum**
7-Feb	0	0	0
12-Feb	0	0	0
14-Feb	0	0	0
18-Feb	0	0	0
21-Feb	0	0	0
25-Feb	0	0	0
28-Feb	0	0	0
4-Mar	0	0	0
7-Mar	0	0	0
11-Mar	0	0	0
14-Mar	0	0	0
18-Mar	0	0	0
21-Mar	0	0	0
25-Mar	0	0	0
28-Mar	0	0	0
1-Apr	0	15	20
4-Apr	0	25	21
8-Apr	0	26	38
11-Apr	0	38	48
15-Apr	0	46	59
18-Apr	28	58	59
22-Apr	41	67	65
25-Apr	52	82	65
29-Apr	59	103	66
2-May	73	107	66
7-May	76	126	
9-May	76	131	
13-May	76	140	
16-May		144	
20-May		146	
23-May		146	
27-May		146	

Figure EA-GU-6



Green-Down Protocol

Purpose

To observe plant green-down and report green-down data to help validate estimates of the end of the plant growing season

Overview

Students monitor the change in color of selected leaves of trees, shrubs or grasses.

Student Outcomes

Students will learn to,

- observe when leaves change color at the end of the growing season;
- compare leaf color with colors in the Plant Color Guide;
- identify tree species native to your area;
- examine relationships between green-down and climate factors;
- Predict when the end of the growing season will occur for upcoming seasons;
- compare color changes of different plant species;
- communicate project results with other GLOBE schools;
- collaborate with other GLOBE schools (within your country or other countries); and
- share observations by submitting data to the GLOBE archive.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is a major source of energy at the Earth's surface.

Life Sciences

Organisms have basic needs.

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Earth has many different environments that support different combinations of organisms.

Plants and animals have life cycles.

Energy for life derives mainly from the Sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Estimating dominant plant species.

Identifying plant species (advanced level).

Observing leaf growth.

Making leaf measurements.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

30 minutes excluding travel time

Level

All

Frequency

At least twice a week beginning two weeks prior to the anticipated start of green-down, continuing until plant color change has ended or leaves have dropped off

Materials and Tools

Grass Green-Down Field Guide and/or *Tree and Shrub Green-Down Field Guide*

Tree and Shrub Green-Up and Green-Down Site Selection Field Guide and/or *Grass Green-Up and Green-Down Site Selection Field Guide*

Tree, Shrub, and Grass Green-Down Data Sheet

Green-Up and Green-Down Site Definition Sheet

Flagging tape, 1 label per student

Compass

Camera

Pencils

GLOBE Plant Color Guide

Green-Down Data Sheet

Fine-tip permanent marker

Preparation

Review dominant plant species of school's GLOBE Study Site.

Prerequisites

Estimating Cloud Cover: A Simulation (from *Atmosphere Investigation*) (suggested)

Green-Up and Green-Down Site Selection

Before selecting your Green-down site, here are some things to consider. Green-up site selection has the same considerations.

1. Your plant phenology site should be in an area where green-up and green-down of native plants is due to climatic factors such as increased temperature or precipitation. Watering and fertilization alter plants' green-up and green-down cycles, and the data would not be representative of natural vegetation and local climate connections. Buildings absorb solar radiation and shelter sites from wind. Therefore, avoid sites near buildings or where watering or fertilization is done. For the phenology protocols, near means that the plant is closer to a building than the height of the building. To determine if the plant is too close to a building, stand at the plant and sight the top of the building through your clinometer. If the angle is greater than 45˚, the building is too close.
2. Non-native species, called exotics, have green-up and green-down cycles that may not be tied to the local climate. Often this is because exotics have not evolved to survive in the local climate. If you are unsure which plants are natives or have evolved to grow in a climate regime similar to yours, ask a local greenhouse or agricultural extension agent, or the appropriate staff at a local college or university.
3. Your green-up and green-down site must be accessible so that students can visit the site at least twice a week. It may be the same as a Land Cover Sample Site or your Atmosphere Study Site. Be sure to determine the location of your site by identifying the latitude, longitude and elevation following the *GPS Protocol*.
4. Because the results of your green-up and green-down measurements may be related to temperature and precipitation data from the *Atmosphere Investigation* and soil moisture and temperature data from the *Soil Investigation*, it is better to choose a site close to the Atmosphere and Soil Moisture Study Sites. The local topography can cause weather to vary even within short distances. This is particularly true in mountainous and coastal regions. The horizontal distance between the Phenology and Atmosphere and Soil Moisture Sites should be less than 2 kilometers and the elevation differences less than 100 meters, so that you can see whether your atmosphere data correlates with your green-up and green-down data.
5. Green-up and green-down detected by satellites are influenced mostly by a few dominant overstory plant species. These will be the species with the largest share of canopy coverage. If you are using a Land Cover Sample Site, you already know the dominant species. If you are using a different site, use the one to three over-story species that are dominant for your region. These over-story plants may be coniferous trees, broadleaf trees, broadleaf shrubs, or grasses. For phenology measurements you should choose a deciduous plant so, if the dominant plant species are all evergreen conifers, use the under-story broadleaf shrubs as your green-up plants. For example, if your study site is 90 percent white pine (a coniferous tree) and 10 percent sugar maple (a broad leaf tree), use the sugar maple trees as the study plants.
6. Scientifically, it is most useful if the tree or shrub branch used for the *Green-Up Protocol* is the same as the one used for the *Green-Down Protocol*. However, you may do only the green-up or green-down measurements or you may use different branches or even different sites if this is necessary to match your educational requirements. If you use different sites for green-up and green-down, create a site definition for each.
7. Since a change in plant growing season may be due to a change in climate, students at your school should try to use the same site, the same plant species, and the same part of the plant consistently, year after year.

Tree and Shrub Green-Up and Green-Down Site Selection

Field Guide

Task

Define the site for green-up and green-down measurement of trees and shrubs.

What You Need

- ❑ *Green-Up and Green-Down Site Definition Sheet*
- ❑ *GPS Data Sheet*
- ❑ *GPS Protocol Field Guide*
- ❑ Flagging tape or other durable identification
- ❑ Dichotomous keys and/or other local species guides
- ❑ GPS receiver
- ❑ Compass
- ❑ Pencil or pen

In the Field

1. Complete the top of the *Green-Up and Green-Down Site Definition Sheet*.

2. Select one tree or shrub. The tree or shrub should be among the dominant native species in your area, deciduous, and easily accessible.

3. Select a healthy and relatively large branch on the south side of the plant in the Northern Hemisphere or the north side of the plant in the Southern Hemisphere. Use a compass or GPS receiver to determine direction. If a lower branch is chosen, it should be on the edge of the stand of trees or shrubs since branches inside a stand may experience a different microclimate due to shading.

4. Identify genus and species using field guides or the help of plant specialists. Record the genus and species on the *Green-Up and Green-Down Site Definition Sheet*.

5. Mark the branch with flagging tape or some other durable identification. Label the flagging tape with a unique number and your name/group name, school name and class.

6. Take a GPS measurement following the *GPS Protocol*.

Grass Green-Up and Green-Down Site Selection

Field Guide

Task

Define the site for green-up and green-down measurement of grasses.

What You Need

- ❑ *Green-Up and Green-Down Site Definition Sheet*
- ❑ *GPS Data Sheet*
- ❑ *GPS Protocol Field Guide*
- ❑ GPS receiver
- ❑ Pencil or pen
- ❑ Nails or stakes or other durable identifiers
- ❑ Meter stick or tape measure
- ❑ Dichotomous keys and/or other local species guides

In the Field

1. Complete the top of the *Green-Up and Green-Down Site Definition Sheet*.
2. Identify genus using field guides or help of plant specialists. Record the genus on the *Green-Up and Green-Down Site Definition Sheet*.
3. Select a one-meter square area dominated by grass plants. Mark your one-meter square plot with nails or stakes or other durable identifiers.
4. Take a GPS measurement following the *GPS Protocol*.

Teacher Support

Advance Preparation

Students should complete the *Estimating Cloud Cover: A Simulation Learning Activity* in the *Atmosphere Investigation* prior to observing green-down. Students will estimate percentage of leaf colors in the green-down observations.

Students should start their observations at least two weeks before expected green-down.

Frequency of Observations

For most areas of the world, there is only one green-up and green-down cycle. However, there are places where multiple wet and dry seasons can occur in a single year, resulting in multiple green-up and green-down cycles. Because of this possibility, we are asking you to report which cycle you are observing. If there is only one cycle, then you report green-down cycle 1. The onset of the first green-down after 1 January is considered green-down cycle 1.

Measurement Procedure

If lower branches are observed, try to sample them from the edge of the stand of trees or shrubs since branches inside a stand may experience a different microclimate due to shading.

In some locations, the end of leaf color change will mark the end of the reporting period.

For each observation, students record the color of the leaf using the GLOBE Plant Color Guide, or if the leaf has fallen or been snow covered. If a leaf has fallen, then no more observations can be made for that leaf. Depending on the snow event, reporting may end as well. The following page shows an example of a completed *Data Sheet.*

Questions for Further Investigation

What other animals (butterflies, waterfowl, songbirds) migrate after plants green-down? When? Why?

Does the timing of green-down occur earlier or later at higher elevations in your region? Why?

Does the timing of green-down occur earlier or later inland or near the coast in your region? Why?

How do fallen plant leaves affect soil properties such as soil color, water-holding capacity, and soil nutrients? How could you find out? Why is this important?

Example of Completed Green-Down Data Sheet

Tree, Shrub, and Grass Green-Down

Date (day and month)	**Leaf 1** (Color, fallen snow covered)	**Leaf 2** (Color, fallen snow covered)	**Leaf 3** (Color, fallen snow covered)	**Leaf 4** (Color, fallen snow covered)	**Reported to GLOBE**
30 September	*5 G 7/4*	*5 G 7/4*	*5 G 7/4*	*5 G 7/4*	☑
3 October	*5 G 7/4*	*5 G 7/4*	*5 G 7/4*	*2.5 Y 8/6*	☑
7 October	*5 G 7/4*	*2.5 Y 8/6*	*5 G 7/4*	*2.5 Y 8/6*	☑
11 October	*5 G 7/4*	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	☑
14 October	*5 G 7/4*	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	☑
16 October	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	☑
20 October	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	*7.5 YR 6/4*	☐
23 October	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	*7.5 YR 6/4*	☐
27 October	*2.5 Y 8/6*	*2.5 Y 8/6*	*2.5 Y 8/6*	*7.5 YR 6/4*	☐
30 October	*2.5 Y 8/6*	*2.5 Y 8/6*	*7.5 YR 6/4*	*7.5 YR 6/4*	☐
4 November	*2.5 Y 8/6*	*7.5 YR 6/4*	*7.5 YR 6/4*	*fallen*	☐
6 November	*2.5 Y 8/6*	*7.5 YR 6/4*	*7.5 YR 6/4*		☐
11 November	*7.5 YR 6/4*	*7.5 YR 6/4*	*7.5 YR 6/4*		☐
14 November	*7.5 YR 6/4*	*7.5 YR 6/4*	*7.5 YR 6/4*		☐
17 November	*7.5 YR 6/4*	*fallen*	*7.5 YR 6/4*		☐
22 November	*7.5 YR 6/4*		*fallen*		☐
29 November	*7.5 YR 6/4*				☐
2 December	*snow covered*				☐
					☐

Tree and Shrub Green-Down Protocol

Field Guide

Task

Observe and record green-down in trees or shrubs.

What You Need

First visit only

- ❑ *Tree, Shrub, and Grass Green-Down Data Sheet*
- ❑ Pencil or pen
- ❑ Camera
- ❑ Compass
- ❑ Fine-Tip Permanent Marker
- ❑ GLOBE Plant Color Guide

Every visit

- ❑ GLOBE Plant Color Guide
- ❑ Pencil or pen
- ❑ *Tree, Shrub, and Grass Green-Down Data Sheet*

In the Field

First visit only/getting started

1. Complete the upper portion of your *Data Sheet*.
2. Locate the leaf at the end of the branch. Label this leaf by marking one dot on the branch next to the leaf stem or petiole. Locate the three other leaves on this branch closest to this terminal leaf.
3. Label these leaves by marking two, three, or four dots next to their stems on the branch.
4. Take a photograph looking in the north, south, east, and west directions.

Every visit

1. Examine each of your four leaves. For each leaf, use the GLOBE Plant Color Guide to estimate the dominant color of each leaf. For example, if leaf 1 appears colored at 60 percent 5G 7/12 and 40 percent 2.5 Y8/10, record the leaf color as 5G 7/12 for that observation date.
2. Record your observations on the *Tree, Shrub, and Grass Green-Down Data Sheet.*
   - If leaf is snow covered, report “snow covered”,
   - If leaf has fallen, report “fallen” and stop reporting after that,
   - Otherwise, continue to report the color until the color stops changing.

Grass Green-Down Protocol
Field Guide

Task
Observe and record green-down in grasses.

What You Need
- ❑ *Tree, Shrub, and Grass Green-Down Data Sheet*
- ❑ Pencil or pen
- ❑ Camera
- ❑ Compass
- ❑ Fine-Tip Permanent Marker
- ❑ GLOBE Plant Color Guide

Every visit
- ❑ GLOBE Plant Color Guide
- ❑ Pencil or pen
- ❑ *Tree, Shrub, and Grass Green-Down Data Sheet*

In the Field

First visit only/getting started
1. Fill in the top of your *Data Sheet*.
2. Look for the four longest green grass shoots.
3. Mark the base of the longest grass shoot with a single dot. Mark the second longest shoot with two dots, the third with three dots and the fourth shoot with four dots.
4. Take a photograph looking in the north, south, east, and west directions.

Every visit
1. Examine each of your four grass shoots. For each shoot, use the GLOBE Plant Color Guide to estimate the dominant color percentage of each shoot. For example, if shoot #1 appears colored at 60 percent 5G 7/12 and 40 percent 2.5 Y8/10, record the shoot color as 5G 7/12 for that observation date.
2. Record your observations for each shoot on the *Tree, Shrub, and Grass Green-Down Data Sheet.*
   - If leaf is snow covered, report "snow covered",
   - If leaf has fallen, report "fallen" and stop reporting after that,
   - Otherwise, continue to report the color until the color stops changing.

Frequently Asked Questions

1. Should I use the same leaves I used for green-up?

If possible, use the same branches or grass plot. If you use other plants try to select plants of the same species. If the plants you use for green-down are at a different location than the ones you used for green-up, then define a new site.

Plant Phenology: Green-Down – Looking At Your Data

Are the data reasonable?

The first step in looking at plant phenology data is to see if the data seem reasonable and make sense. You should stop reporting for your selected leaves after the leaves fall off the trees or shrubs or when the leaves have stopped changing color. Figure EA-GD-1. shows the green-down data for Escuela de Ensenanza Media 7 Nicolas Copernico in Buenos Aires, Argentina. See how the leaves change color as the green-down season continues. The data collection ends after the leaves fall off. (Also notice the green-up data – it shows how fast the leaves grow, however, it would be good to know when budburst occurred and when leaf growth stopped.)

Table EA-GD-1 shows a table of green-down data for another school.

Date	Leaf number	Leaf State	Color
20021021	1	F	
20021021	2	F	
20021021	3	F	
20021021	4	C	2.5Y:8/12
20021024	1	C	5GY:4/8
20021024	2	C	5GY:5/10
20021024	3	C	5GY:7/12
20021024	4	C	5GY:4/10

For leaves 1, 2 and 3, color is reported after the leaves fell off the tree. This may be an error in the data. Perhaps the dates were recorded incorrectly and what is reported for October 24 was meant to be for October 21. One way to find out is to contact the school and ask the teacher and students.

Also, notice for leaf 4, there are two observations of color. It was yellow on October 21 (2.5Y:8/12) and then was green again on the 24th (5GY:4/8). Were the dates reported incorrect as may have been the case for leaves 1,2,3?Did the leaf continue to change color? If so, how did it change color and for how long? Did it fall off the tree? From the data reported we cannot know.

What do scientists look for in the data?

Scientists are very interested in when leaves appear in spring and how quickly they expand. The timing and rate of fall leaf changes, such as color changes and leaf drop, are also important. It may seem strange that such easy to observe and common events are important for Earth System Science, but they are. These plant phenological events are directly related to global carbon fixation and the amount of carbon dioxide in the atmosphere. Also they affect and are affected by air temperature and humidity and soil moisture.

For example, many scientists use data from a NASA sensor, the Moderate Resolution Imaging Spectrometer (MODIS), to monitor the seasonal dynamics of vegetation. Green-up/green-down data gathered by GLOBE students, using consistent methods all over the world, are one of the best tools with which to verify the accuracy of these satellite products.

Computer models are one of the main research tools used by scientists to predict the future climate of the planet. Seasonal vegetation patterns and activity is an important component of this research. Many models contain programs that are used to predict the expansion of plant leaf material. Without data against which to compare these models, we cannot believe the model predictions. By using GLOBE green-up/green-down data to help develop these models, scientists will be able to better predict our future climate.

Some applications of GLOBE data can be very specific, in particular when plant phenology is linked to other events. Many plant pests like gypsy moths appear during certain leaf developmental stages. By linking GLOBE green-up data with the appearance of gypsy moths, scientists are working to develop better pest treatment approaches.

In short, by participating in the GLOBE *Green-Up and Green-Down Protocols,* you will be helping to gather data that scientists will use in many fields of Earth System Science, sometimes in unpredictable ways!

An Example of Student Research

A teacher asked the students why do leaves change color in the fall? The students looked at each other and weren't sure why. One student commented that he never thought about it and said that he just took it for granted - leaves turn color in the fall and eventually fall off the trees. After discussing reasons why leaves turn color and eventually fall off in preparation for the dormant vegetation stage during the winter season, the teacher asked if all leaves on all trees turn the same color. The students didn't think so because some trees are red, others are orange, and others are brown or yellow. As a homework assignment, the teacher asked her students to look at green-down data on the GLOBE Web site and make some observations about how leaves turn color in the fall.

The students were somewhat familiar with the GLOBE maps and graphs and realized that sites are defined for all the data students collect. So, they wanted to see if there were any nifty maps or graphs for phenology sites. After clicking on *Maps and Graphs* on the navigation bar, they clicked on *GLOBE Sites* and then, *Green-up/Green-down Site Visualization*. The new page listed phenology sites organized by country. They scrolled through the list of countries and schools and decided to look at green-down data at Suomussalmen Lukio school in Finland. At Suomussalmen Lukio there are 10 phenology sites. They found after looking at graphs of the data for each phenology site that students at Suomussalmen Lukio are collecting phenology data for different species —*Alnus incana*, *Larix deciduas, Betula pubescens*, *Populus tremula*, *Calamagrostis*, and *Betula pendula.* They decided to look more closely at three species at three sites shown in Figures EA-GD-2, EA-GD-3 and EA-GD-4: Figure EA-GD-2 (site GRN-01) with *Alnus incana*, Figure EA-GD-3 (site GRN-02) with *Betula pendula*, Figure EA-GD-4 (site GRN-03) with *Larix decidua*. They also examined the data table that is given in the GLOBE Web site after each graph.

The students made numerous observations.

1. The initial green colors at the start of green-down observations were the same for *Alnus incana* and *Betula pendula* but were different for *Larix deciduas*. They looked at the table of data at the bottom of the graphs for each site and saw that the first two species started with a color of 5GY:4/8 and *L. deciduas* started with 5GY:7/12.
2. The leaf color for *A. incana* did not change much and remained a dark green until the leaves were lost or fallen.
3. The leaf color for *B. pendula* went from dark green to light green, then yellow. Two of the four leaves turned brown before lost or fallen, whereas the other two were more yellow.
4. *L. deciduas* went from a light green to yellow and then orange for three of the leaves. The fourth leaf remained a yellow color.
5. The leaves were lost or had fallen off the different trees on different days. The leaves for *A. incana* fell off around October 3; those for *B. pendula* around September 28 and *L. deciduas* around October 27.

The students concluded that different trees showed different color patterns during the fall. They completed their homework assignment to make some observations on how leaves change color in the fall, but instead of wanting to move on to another topic in class, the students had many more questions!

One student commented that they were only looking at data collected for one year. Will green-down start and end at the same time next year? Another student asked if each tree species showed the same color changes each year. What happens when there is an unusually dry or cold fall? A third student wanted to know if the same color changes will be found for these species at different locations in Finland as well as other countries.

To answer some of their questions, they decided to contact someone in their community who knows about the local vegetation to find out more about the tree species growing around them. As well, they would do a search for other GLOBE schools to see if they can find green-down data for these species. Then they would compare the color changes of the same species at different locations. They predicted that the same species would change colors in the same way at different locations. They decided to do an experiment: they would select native trees in their area and see if students in another area have been collecting green-down data for the same species. They will observe green-down during the next fall. They predict that the colors of the leaves during green-down for the tree species they select will be very similar to the colors observed by other students in a different area for the same tree species.

Figure EA-GD-1

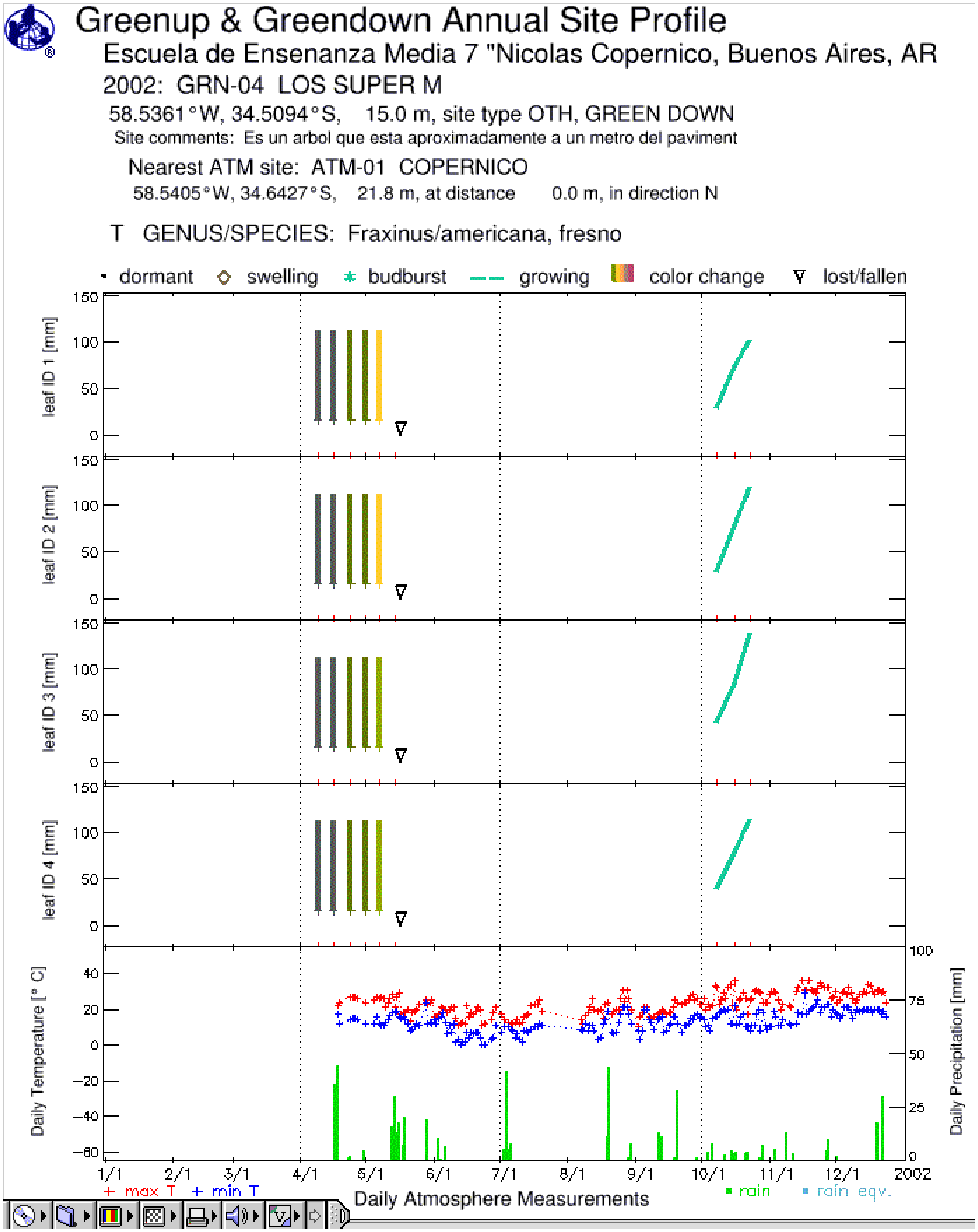


Figure EA-GD-2

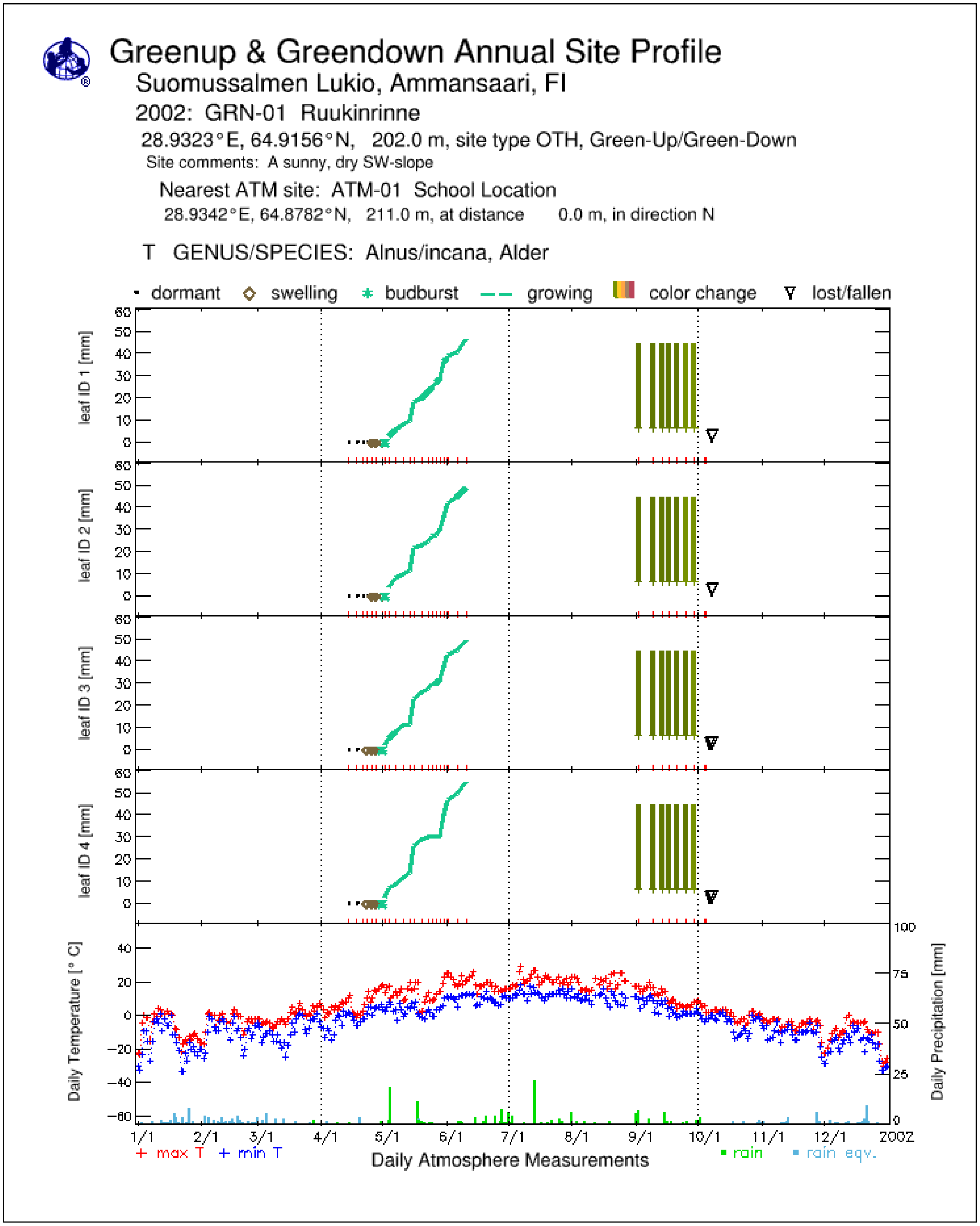


Figure EA-GD-3

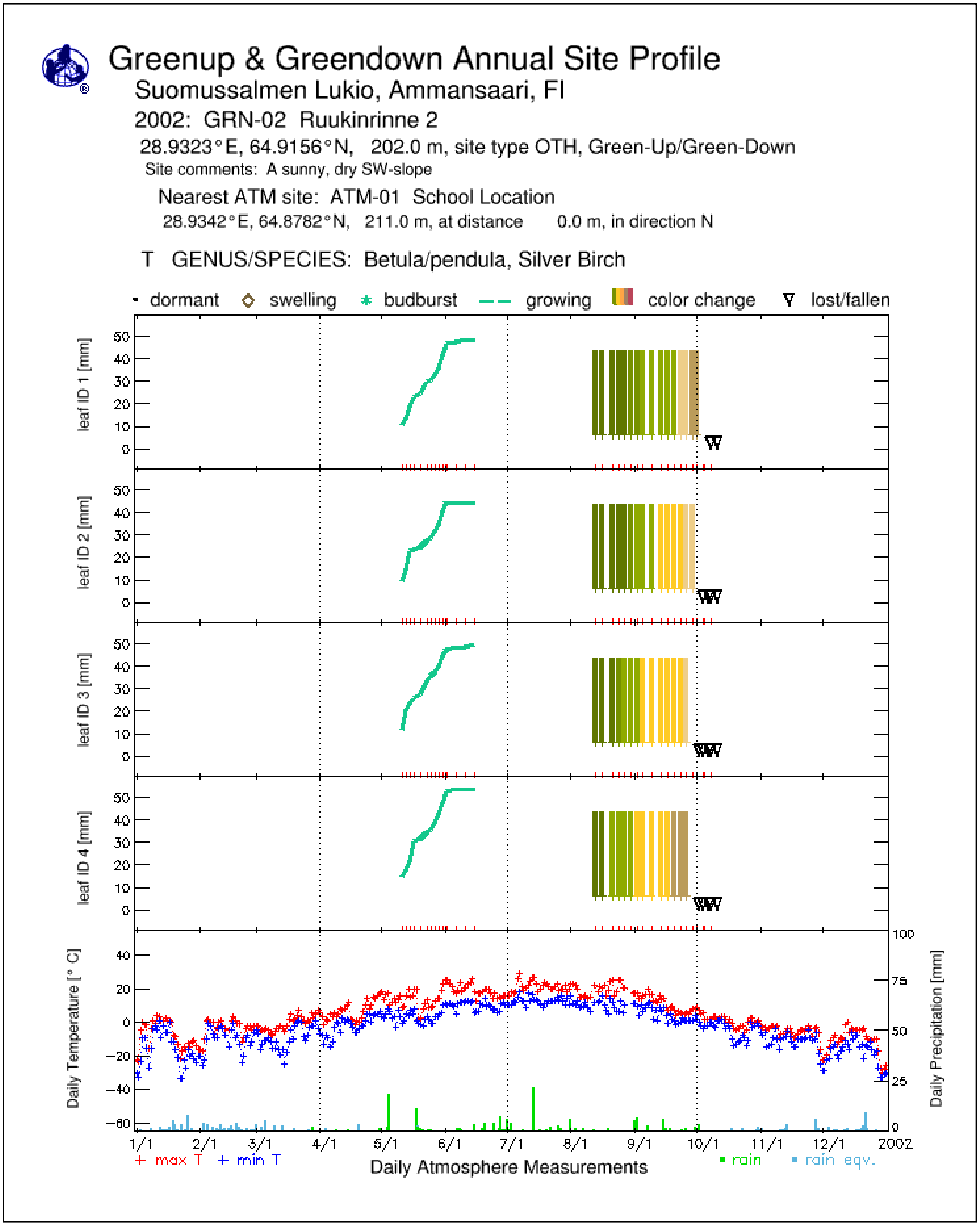
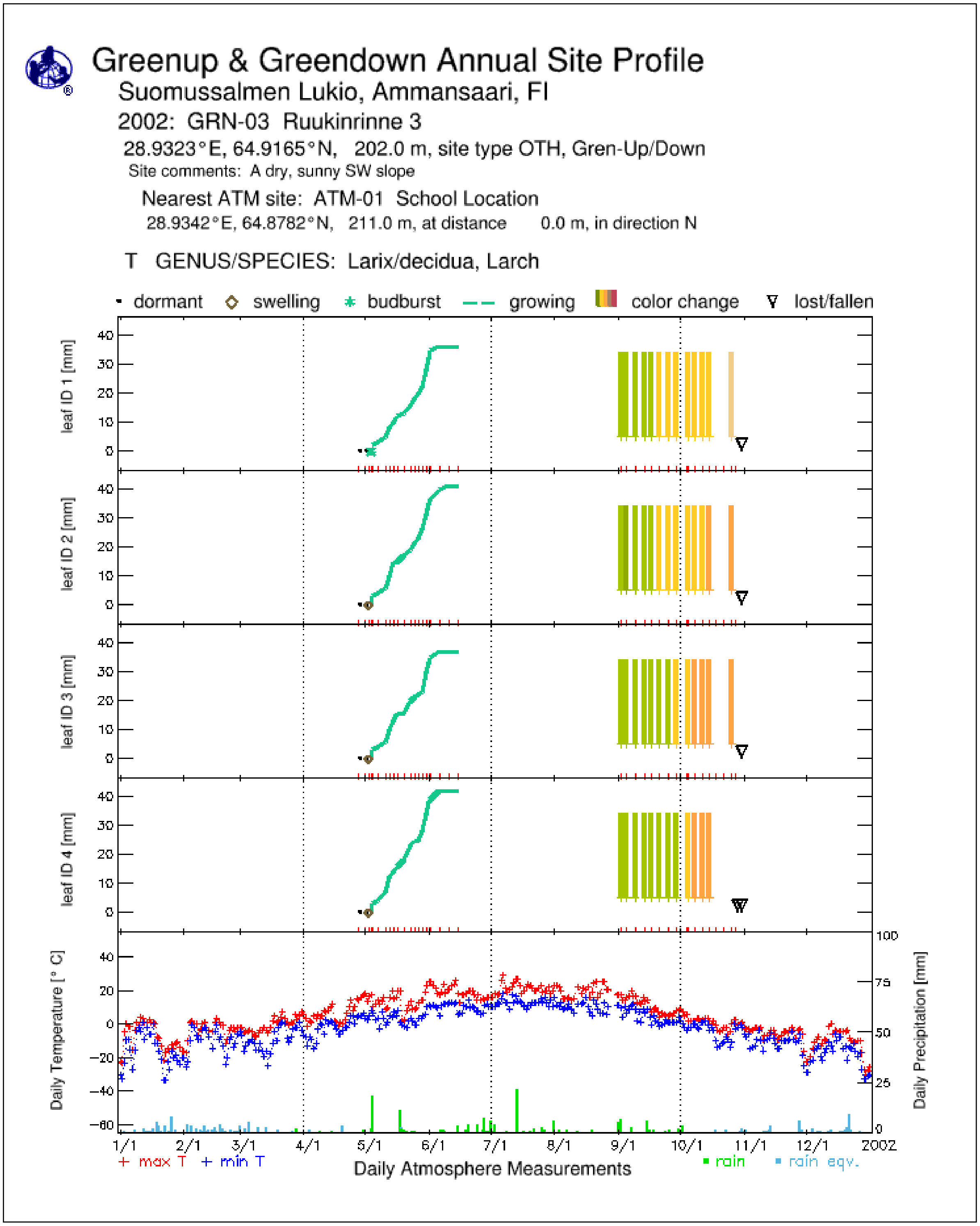


Figure EA-GD-4



Operation Ruby Throat: The Hummingbird Project Protocol

Purpose

To observe seasonal migration patterns, feeding habits, and nesting behavior of Ruby-throated Hummingbirds *(Archilochus colubris)* in North and Central America

Overview

Students in the U.S. and Canada collect data for one or more of the following special measurements for Ruby-throated Humming birds (RTHUs):

- Observe first Spring sighting of migrant RTHU.
- Make daily observations.
- Record RTHU sightings throughout hummingbird season (Spring through Autumn).
- Observe final departure date of RTHU migrant in Autumn.
- Count number of RTHU visits to hummingbird feeders and/or to flowers, or compare bird feeder versus flower visits.
- Identify different species of flowers in a hanging basket, flower basket, garden, or natural area and count number of RTHU visits to those species.
- Observe nesting behavior.
- Report "unusual" hummingbirds that are color-marked, have abnormal plumage, or that occur out of normal range.

Students in Mexico and Central America collect data similar data to the above except:

- First sightings of returning RTHU are in Autumn.
- Final departure date is in Spring.
- Nesting behavior does not occur in the tropics.

Student Outcomes

All students will learn about hummingbird natural history and ecology. Students will learn how to identify and age male and female Ruby-throated Hummingbirds and to observe migration and feeding behavior. Students will learn how to make connections among hummingbird behavior and weather, climate, food availability, seasonality, photoperiod (day length), and other environmental factors.

Science Concepts

Life Sciences

Organisms can only survive in environments where their needs are met.

Plants and animals have life cycles.

Some animals, through migration, spend parts of their life cycles in different ecosystems.

Reproduction is a characteristic of all living organisms.

Functions of an organism relate to and change the nature of its environment.

Interaction among organisms in an ecosystem results in adaptive change in organisms over time.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an "ecosystem".

Organisms both cooperate and compete in ecosystems.

Organisms living together and the physical factors with which they interact constitute an ecosystem.

Geography

How to use maps (real and imaginary).

The physical characteristics of place.

The characteristics and spatial distribution of ecosystems.

How human modify the physical environment.

Science Inquiry Abilities

Identify, age, and sex Ruby-throated Hummingbirds (RTHUs).

Count living, moving hummingbirds.

Identify flower species.

Plant and care for Hummingbird Habitats (optional).

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate math to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternate explanations.

Communicate procedures and explanations.

Time

Sightings: Any time during day

Bird feeder and Flower Visits: 45 minutes at same time of day

Flower Species Visits: 45 minutes minimum at same time of day (if possible make observations for several consecutive hours)

Frequency

First Spring Sighting: Daily for three weeks (beginning approximately mid-March in southern U.S., later in northern U.S. and Canada)

Last Spring Sighting (Mexico and Central America): Specific time frame not known; approximately 1 February through Mid-March

Sightings Through Seasons: Daily preferred

Bird feeder and Flower Visits: At least two times each week (daily, if possible, from approximately 1 April to 1 October in the U.S. and Canada, remainder of the year in the tropics)

Last Autumn Sighting: Daily (preferred) for three weeks (approximately late September until mid-October)

First Autumn Sighting (Mexico and Central America): Specific time frame not known; approximately mid-August through mid-October

Nesting behavior: Daily if a nest is found (approximately mid-April through early August; nesting occurs only in U.S. and Canada)

"Unusual" hummingbirds: When sighted

Level

All

Materials and Tools

Hummingbird Data Sheets

GPS Data Sheet

GPS Field Guide

Calculator (optional)

Camera

Hummingbird feeder and food (optional if hummingbird flowers are used)

Hummingbird flowers (optional if hummingbird feeder is used)

Clipboard

Pencils and pens

Binoculars (optional)

Bird identification guide

Wildflower identification guide (optional)

Cultivated flower identification guide (optional)

GPS receiver (may be borrowed)

Compass

Preparation

Learn how to identify male, female, and immature Ruby-throated Hummingbirds, using bird identification guides and information on the Web site for Operation *RubyThroat: The Hummingbird Project at* www.rubythroat.org.

Prerequisites

None

The Hummingbird Project Protocol – Introduction

Have you ever noticed those colorful little birds that fly around flowers in gardens or meadows? They seem to never stop, moving from one flower to the next; they almost look like very large insects. These tiny birds are hummingbirds—fascinating creatures that are common in many areas but about which there is much to learn. When do they migrate in the Spring and Autumn? How do storms affect their migration? Can you imagine how a strong wind might blow these miniature light-weight creatures away from their intended path? Do they even—*have*—an intended path?

Scientists want to learn about their migration patterns as well as their eating and nesting behavior. What flowers do they prefer to visit for sweet nectar? Will they come to a hummingbird feeder in your schoolyard? How do adult hummingbirds care for their eggs and young hummingbirds after they hatch? One commonly seen hummingbird is the Ruby-throated Hummingbird. Does behavior within this bird's nesting range in Canada and the United States differ from that on its wintering grounds in Mexico and the seven countries of Central America? Your observations may help answer these kinds of questions and greatly help scientists while you enjoy studying hummingbirds and their habits.

When you observe hummingbirds you are also helping scientists to better understand how animals may be responding to weather and longer term climate change. Hummingbird migration, nesting, and eating behavior are affected by temperature, precipitation, land cover, and many other things. Taking other GLOBE measurements along with hummingbird observations will lead to interesting projects and important science findings in which you can be an important participant.

Have fun while learning about hummingbirds and the natural world around you!

Background

The Ruby-throated Hummingbird (*Archilochus colubris*) is an ideal species for a cross-disciplinary science study involving students from Canada, Mexico, the United States, and all seven Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama). Known in Spanish as *mansoncito garganta de fuego* or *chupaflor rubi*, rubythroats are the most widely distributed of all hummingbirds. They come readily to artificial feeders and are tolerant of humans. Ruby-throated Hummingbirds are fascinating creatures that immediately capture a student's imagination and lead him or her into scientific investigation and discovery. Information and photos about RTHU biology, behavior, and ecology can be found on the web site for Operation *RubyThroat: The Hummingbird Project* at www.rubythroat.org.

Ruby-throated Hummingbirds (RTHUs) are Neotropical migrant insect- and nectar-eaters that range from Central America to Alberta, Canada and from the east coast of the United States to the middle of the Great Plains. They breed in the eastern U.S. and southern Canada and winter over from Mexico south to the Panama Canal (occasionally in southern Florida and along the U.S. Gulf Coast and very rarely elsewhere in the continental U.S.). Figure EA-RT-1 shows the species' distribution. Scientists do not know exactly how far north RTHUs breed, so Canadian students who live near the northern edge of the map's red area can provide important information about the species' actual range.

RTHUs also occur rarely during the non-breeding season in parts of the Caribbean Region; there has been at least one report from each of the following islands: Bahamas, Bermuda, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, and Puerto Rico. Schools at these locations are encouraged to participate in Operation RubyThroat, with the understanding that hummingbirds they see likely will not be RTHUs. Nonetheless, if Caribbean students are alert for RTHUs, there is a possibility they will see one and contribute significantly to our understanding of RTHU winter ranges. Ornithologists are always alert for possible range extensions, especially during times of environmental change.

Migration and overwintering patterns in RTHUs are poorly understood. Some experts speculate that RTHUs follow similar routes for both northward and southward migrations, with some birds flying non-stop across the Gulf of Mexico and others going overland through Mexico. In some years, RTHUs appear to move northward at approximately the same rate as the 1.7 degree C isotherm, which may correlate with availability of small insects and flowering times of several temperate plant species that provide energy-rich nectar.

RTHU migration details remain a mystery. We do not know specifically where populations from various parts of North America overwinter since no one in Mexico or Central America has reported a RTHU banded in the U.S. or anywhere in the tropics. In fact, only about a dozen of the more than 50,000 RTHUs banded in the U.S. and Canada have been recaptured or found dead and reported from sites within the continental U.S.

The first RTHU ever recaptured more than 15 kilometers away from its banding site was a young male banded and color-marked in late September 1991 at Hilton Pond Center for Piedmont Natural History near York, South Carolina, and re-trapped 10 days later near Atlanta, Georgia. Color-marked birds from Hilton Pond also have been seen or retrapped in Mobile, Alabama, and in Cameron, Louisiana.

Figure EA-RT-1: Distribution of the Ruby-throated Hummingbird (Archilochus colubris). RED—Breeding Range; BLUE—Winter Range; GREEN—Year-round Range

It is not clear what triggers the onset of RTHU migration toward the north in Spring and back south in Autumn; photoperiod (length of day) appears to be a major factor. We do not understand the effects of local or regional weather and there are no scientifically useful data about the actual impact of tropical storms and hurricanes on the trans-Gulf Autumn migration of RTHUs. Winds may influence Spring migration to the breeding grounds, but no one has explored this possibility. Likewise, no one has studied extensively how RTHU migration movements may be affected by the end of flower production or by land cover changes in the tropics or North America.

Some participants in the U.S. or Canada will be fortunate enough to find an active RTHU nest. If this happens, students may conduct an in-depth observation of nesting behavior. Be careful not to disturb the nest and please do not report an old or abandoned nest where no activity is seen. Although RTHUs have the widest breeding distribution of any of the 338 hummingbird species, there is still much to be learned about their nesting behavior. Males are not believed to build nests, incubate eggs, or care for nestlings, so any observation of adult male activity near the nest is potentially important. Female RTHUs have been known to lay a second or third clutch of eggs in one breeding season, but it is not clear whether this behavior occurs regularly or because an earlier nest fails from predation or other interference. Little is known about the relationship between re-nesting, weather, and altitude or geographic latitude.

Very little is known about RTHU behavior on the wintering grounds, including what plants the birds use for nectar, whether they defend feeding territories, or how they interact with the many other hummingbird species that are permanent residents in the tropics. Schools in Mexico and Central America can make significant contributions to the understanding of RTHU behavior just after the birds arrive in Autumn migration, during the months RTHUs are on their non-breeding grounds, and just prior to when RTHUs depart for their trip north.

Although most hummingbirds observed in the eastern half of the U.S. will be "normal" RTHUs, students may encounter "unusual" hummingbirds. These include:

1. RTHUs with abnormal pigmentation, especially albinos, partial albinos, and leucistic individuals (detailed descriptions in the next section);

2. RTHUs that have been color-marked with dye or paint as a way to study their migration patterns; or,
3. Vagrant western, Mexican, or Caribbean hummingbird species other than RTHUs that wander into the eastern U.S. and Canada, particularly in Autumn and Winter.

It is important to record sightings of these "unusual" hummingbirds on GLOBE *Data Sheets* and to immediately report the sightings to research@hiltonpond.org or (803) 684- 5852. If possible, please take photographs. Photos and descriptions of some of these "unusual" hummingbirds follow the section below that describes typical RTHUs.

Ruby-throated Hummingbird (RTHU) Identification

Common Characteristics

All RTHUs have backs, foreheads, wings, and tails that are dark iridescent green. Adult male RTHUs (Figure EA-RT-2) have iridescent red coloring on the throat, called a "gorget", while adult females typically have white throats (Figure EA-RT-3); this makes it easy to determine a bird's sex in Spring when only adult birds are present. Although very rare, an adult female will show light streaking on her throat in early Spring; however, she is still easily differentiated from the adult male with his red throat. Sometimes in dim light the iridescent red and green appear black or brown, so it is important to try to make observations under good lighting conditions.

Newly hatched male and female RTHUs do not have red on their throats; they both resemble adult females, making it difficult to determine sex or age among white-throated birds during late Spring, Summer and Autumn. However, young males sometimes have throats streaked with green or black and some even acquire a few red throat feathers prior to Autumn migration (Figures EA-RT-4 and EA-RT-5).

Young males and females of any age have white tips to their outer tail feathers. RTHU males of any age are typically up to 25% smaller than females, but size should not be used as a factor when sexing hummingbirds. Please visit www.rubythroat.org/RTHUExternalMain.html for more hints on determining sex in RTHUs.

RTHUs undergo feather molt on the wintering grounds in Mexico and Central America. Prior to Spring migration, young males hatched during the preceding breeding season develop a full red gorget. They, as well as adult males and females of any age, replace all wing, tail, and body feathers. Female RTHUs resemble females of several other hummingbird species that occur in the tropics, so it is very difficult to make positive identifications of them during Winter in Mexico and Central America; adult male RTHUs can be identified more easily. Please be cautious in reporting that hummingbirds observed in winter in the tropics are RTHUs.

RTHUs with unusual plumage

RTHUs sometimes exhibit color patterns that are very different from their normal green, white, and red. Albino RTHUs are very rare and are completely white with pink eyes, bill, and feet. Occasionally there are also "leucistic" forms that have normal black eyes, bill, and feet (Figure EA-RT- 6), but in which some or all the feathers are white, gray, or otherwise abnormally colored. (Figure EA-RT-7). Nothing is known about the behavior of albinistic or leucistic RTHUS during Autumn migration or on the wintering grounds. Curiously, none of these birds that have been banded in the U.S. have ever returned in a later year. It is not known whether these abnormally colored birds die in migration or are simply unable to compete with other hummingbirds in the tropics. Visit www.rubythroat.org/AlbinoMain.html for more information about hummingbirds with unusual coloration.

Color-marked RTHUs

As part of *Operation RubyThroat: The Hummingbird Project,* RTHUs captured and banded at Hilton Pond Center for Piedmont Natural History near York, South Carolina, are color-marked with temporary green dye on the upper breast or throat (Figure EA-RT-8). Birds banded at other locales through *Operation* RubyThroat may be marked with other dye colors. A few hummingbird banders working on other projects use different color-marking schemes, including the placement of a bright paint dot on the top of the bird's head. RTHUs sometimes accumulate large amounts of yellow, orange, or white pollen on their heads, throats, and upper breasts; these deposits should not be confused with color-marking.

If possible, take a photo of any color-marked hummingbird and try to determine whether it is banded on the left or right leg. Accurate sightings of these color-marked birds are very valuable in helping us understand Spring and Autumn migration patterns of RTHUs even if the bird is not recaptured by a licensed hummingbird bander in your area. Students in Mexico and Central America should be especially vigilant for color-marked RTHUs, since a RTHU banded and marked in the U.S. or Canada has never been reported from the tropics. For more details about the color-marking project, refer to www.rubythroat.org/NewsRFIColormark00Sp.html.

Winter Vagrant Hummingbirds: United States and Canada

RTHUs are the only hummingbirds that regularly breed in the region shown in red in Figure EA-RT-1; this includes 38 states east of the Rocky Mountains, plus the District of Columbia and southern and eastern Canada. Nonetheless, several western U.S., Mexican, and Caribbean hummingbird species have been known to wander eastward, especially during Autumn migration, and a few vagrant hummingbirds winter over each year in the eastern U.S. At least ten species of hummingbirds from the western U.S. have been verified east of the Rocky Mountains during Winter.

In the eastern U.S. the most likely Autumn and Winter vagrants are Rufous Hummingbirds (see Figures EA-RT-9 through EA-RT-12). Other possible species include, but are not limited to: Anna's Hummingbird, Black-chinned Hummingbird, Blue-throated Hummingbird, Broad-billed Hummingbird, Broad-tailed Hummingbird, Buff-bellied Hummingbird, Calliope Hummingbird, Green Violet-ear, and Magnificent Hummingbird. Adult males of these species cannot be confused with adult male RTHUs, but young males and females sometimes cannot be identified to species unless captured, measured, and examined closely by a licensed hummingbird bander. Observers in states along the Gulf of Mexico may see unusual hummingbirds that wander in from Mexico or the Caribbean.

If you are in the eastern U.S. or Canada and sight a species other than a RTHU at any time of year—or if you see **ANY hummingbird in that region from 15 October through 15 March—**please contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803)684-5852. It is important to report these vagrant birds immediately because they often stay in an area few only a few days and then move on to another site. Also record your observations on your Hummingbird *Data Sheets* and take photos of the hummingbird if possible; be sure to include notes about the bird's color and other markings.

For photographs and descriptions of some other hummingbird species that may occur in your study area, see www.rubythroat.org OtherSpeciesMain.html,
and refer to
www.rubythroat.orgResearchHummerVagrantMain.html)

Figure EA-RT-2a: Adult male Ruby-throated Hummingbird, with full red gorget

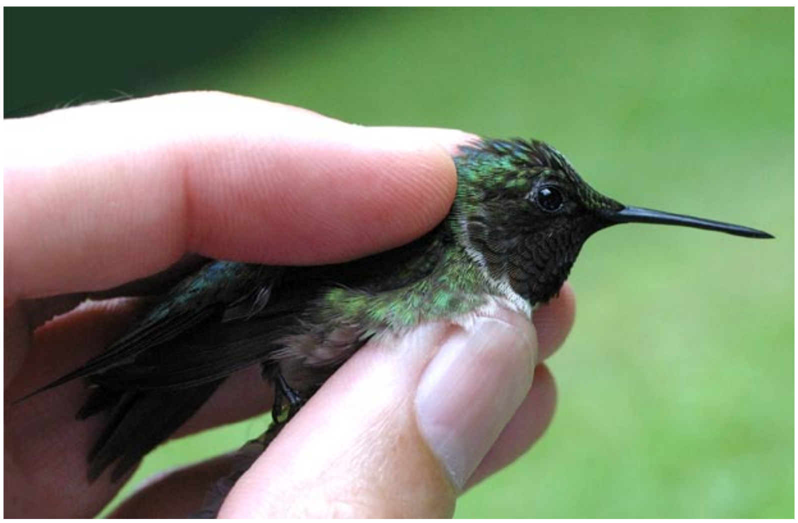


Figure EA-RT-2b: The red gorget of the adult male Ruby-throated Hummingbird appears black when viewed from the side or in poor light.

Figure EA-RT-3: Adult female Ruby-throated Hummingbird, with unmarked white gorget (Young female RTHUs and most young males also have unstreaked white throats.)

Figure EA-RT-4: Young male Ruby-throated Hummingbird, with throat streaking.

Figure EA-RT-5: Young male Ruby-throated Hummingbird, with few red gorget feathers and throat streaking.

Figure EA-RT-6: Heavily leucistic Ruby-throated Hummingbird, with white feathers, black bill, and black eyes. True albinos have white plumage with pink bill, eyes, and feet.

Figure EA-RT-7: Partially leucistic Ruby-throated Hummingbird, with buffy and brown feathers.

Figure EA-RT-8a: Female Ruby-throated Hummingbird with green color marking on throat and upper breast.

Figure EA-RT-8b: Front view of color marked female Ruby-throated Hummingbird. Note very faint gray streaking that is sometimes visible on the female's throat.

Figure EA-RT-9: Adult male Rufous Hummingbird (Selasphorus rufus), with band on right leg. Note overall rusty coloring on back and belly. Viewed from front, gorget is iridescent orange (rather than red of Ruby-throated Hummingbird). This species breeds in western Canada and northwestern U.S. and normally winters in Central Mexico. Female and young male Rufous (Figures 10, 11a, 11b) are far more likely to be seen than adult males in Autumn and Winter in the eastern U.S. (Photo courtesy of Carl Sewell.)

Figure EA-RT-10: Female Rufous Hummingbird. Note rusty sides, rust at base of tail (sometimes hidden), and scattered greenish or metallic-greenish feathers on gorget (Notice band on the bird's right leg.)

Figures EA-RT-11a : First-year male Rufous Hummingbird.

Note streaking on throat, hints of rust especially at base of tail, streaking on throat, and sometimes one or more iridescent orange gorget feathers —not red as in the Ruby-throated Hummingbird. Among Rufous Hummingbirds, females and young males vary considerably in the amount of rust color in their plumage. Many individuals may not look like the ones in the photos above.

EA-RT-11b

Teacher Support

Who can do this protocol?

Operation RubyThroat: The Hummingbird Project is open to students in the U.S., Canada, Mexico, and all seven countries of Central America. Please encourage fellow teachers at schools in these states and countries to participate. Home-schooled students, nature centers, Summer camps, senior citizen centers, and other individuals are also welcome to participate in the project.

Site Selection

Hummingbird sightings can be made anywhere in your community, but it is best to select one location and repeat observations at that site. Multiple locations can be established throughout your community. Use the *Hummingbird Site Definition Field Guide* and *Hummingbird Site Definition Data Sheet* to define a unique site definition for each location.

You can create a hummingbird habitat in different ways:

1. A hummingbird feeder can be in the schoolyard, hung outside the classroom window, in a park or other public area, or in someone's yard. It should be easily accessible for frequent visits, proper maintenance, and easy observation.
2. Flowers can be anywhere in your community: in a planted and maintained garden, in a flower box or hanging basket, or in a natural area. Hummingbird flowers come in all colors and shapes, but many of them are red and tubular. The web site for *Operation RubyThroat: The Hummingbird Project* has illustrated lists of ten native and ten exotic hummingbird flowers and hints for cultivating them (see www.rubythroat.org/FoodMain.html).
3. Students may plant and care for a Schoolyard Hummingbird Habitat, or for a garden plot elsewhere in the neighborhood. Master Gardeners or local garden clubs may be interested in assisting with such a project. If you plant a habitat, be sure it can be cared for during summer months. Hints for landscaping for hummingbirds are at www.rubythroat.org/LandscapingMain.html.

Students are encouraged to continue observations during vacations, even if teachers cannot directly supervise them. Students can use their home addresses as reporting stations.

Advance Preparation

Most likely there are bird experts in your community (for example, a local Audubon chapter, Sierra Club group or at a wild bird specialty store). Some of these may be willing to work with students on hummingbird projects, particularly if daily observations are made throughout the Summer. Local bird experts can provide information about the average dates that RTHUs arrive and leave so that students will know approximately when to start looking in earnest.

For US and Canada Schools: If you plan to incorporate hummingbird protocols into your fall curriculum, hang and maintain a hummingbird feeder near your classroom in early August before school begins. Late Summer and Autumn are the busiest time for RTHUs in the U.S. and southern Canada, and having a feeder out before the school year starts will allow your students to conduct up to a month of observations before the RTHUs migrate further south for the Winter.

RTHUs rarely winter in southern Florida and in states along the Gulf of Mexico; a few have been reported elsewhere during Winter in the U.S. In Spring northward migration, most RTHUs apparently depart from Mexico and Central America by mid-March. The earliest birds get to the Gulf Coast states about 1 March and move northward over the next several weeks. There is some indication there may be two waves of RTHU migration into the U.S., one in late March and another up to a month later.

For Mexico and, Central American Schools: Although several factors make identifying and observing RTHUS in Mexico and Central America more difficult than in the U.S. and Canada, students in the tropics actually have opportunities to report Winter RTHU behaviors about which scientists know little or nothing. These students can also answer questions about when RTHUs arrive from more northern areas in the Autumn migration and depart the tropics during Spring migration. Since Mexico and Central America are home to some hummingbird species that do not migrate, schools in those countries may elect to maintain feeders or nectar-bearing plants to observe general hummingbird behavior on a year-round basis.

In the U.S. and Canada, RTHUs begin their Autumn southward migration as early as the first of August, but no one knows exactly when they begin to show up in Mexico and Central America. Large numbers of hummingbirds are known to assemble along the Gulf Coast in early September. Students in the tropics should begin looking for RTHUs around the end of the first week in August, but it may be that the first arrivals will not appear until a month after that.

In Spring, northward migration, the first adult males RTHUs begin arriving in the Gulf Coast states around the first week in March. Trans-Gulf migrants from Mexico would need to depart just prior to that, since a non-stop flight from the Yucatan Peninsula to the U.S. Gulf Coast takes only about 20 hours. It is not known when RTHUs that overwinter as far south as Panama first begin to move northward, but the first of February seems like a good guess.

Although it appears that many RTHUs fly across the Gulf of Mexico in both Spring and Autumn, it may be that some migrate overland through Mexico. Thus, schools along Mexico's Gulf Coast should look for migrant RTHUs during both migration periods, in the hope of finally answering the question of whether some RTHUs do not cross the Gulf.

Supporting Protocols

Through *Operation RubyThroat: The Hummingbird Project* your students will learn many things about the behavior and ecology of Ruby-throated Hummingbirds (RTHUs). By collecting additional GLOBE data about atmosphere, climate, hydrology, soils, and phenology, your students also may discover new relationships between RTHUs and factors that affect them. As students study RTHUs and other GLOBE protocols, they will undoubtedly ask many questions about these tiny birds and their environment. If they are unable to answer the question through observations or by referring to GLOBE materials or the *Operation RubyThroat* Web site (www.rubythroat.org), you should feel free to contact the project's principal investigator via GLOBEMail or projects@rubythroat.org.

Supporting Activities

Ruby-throated Hummingbirds can be used as a focus for integrated studies of atmosphere, phenology, land cover, botany, animal behavior, geography, and other disciplines. Encourage fellow teachers in all subject areas to participate with you and your students in Operation RubyThroat. For hints on cross-disciplinary activities, see www.rubythroat.org/ActivitiesXDisciplineMain.html. The most successful implementations of *Operation RubyThroat* have been school-wide projects in which every student and teacher was involved in some way.

Have students explore neighborhoods in different seasons around the school. Look for natural and cultivated plots containing hummingbird flowers such as Trumpet Creeper, *Campsis radicans* (see below), a common but important food source throughout much of the RTHU's breeding range. Ask students where they are able to find the most hummingbirds.

Hummingbird observations are also an excellent activity for summer enrichment programs at schools, camps, and nature centers, or for home-schooled students.

Managing Students

Special Measurements of feeder and flower frequency require observations for a continuous block of 45 minutes. Students working in a group can take turns making observations so that no student gets tired or bored.

Management Procedure

Which Hummingbird Protocol To Do

There are several different hummingbird protocols to choose from and the one or more protocols you choose will depend on the amount of time you have and your educational objectives. Some protocols can be mastered by very young students, while others require more advanced skills and vocabulary. All protocols are designed to help scientists gain a better understanding of RTHU ecology and behavior. Any observations your students make have value, and there is real potential that your students may make an original discovery about RTHUs—especially in Mexico and Central America.

Hummingbird Sighting Protocol: This is easy and requires little or no preparation other than teaching the students how to recognize a hummingbird. After some practice, students will be "looking out" for hummingbirds wherever they go throughout the day whether they are in school or not.

These simple observations are important to estimate the size of local RTHU populations and how these populations change throughout the year. They also help pinpoint when hummingbirds arrive or depart during migration and whether they are just passing through the area in which your school is located. At the beginning or end of the migration period, the only reliable way to know when the last RTHU arrives or departs your area is to make observations every day.

Feeder Visit Protocol: This protocol requires a hummingbird feeder and simple maintenance of it. The feeder food needs to be replenished periodically. The feeder will cause hummingbirds to gather and increase student opportunities to observe and identify different ages and sexes of RTHUs.

In this protocol students count the number of times hummingbirds visit feeders in a 45-minute block and learn how their data may be used to indicate the number of RTHUs in an observation area. Students may notice that an individual RTHU will vigorously defend a feeder and try to drive away other hummingbirds. Students may question the accuracy of their data and conclude that there may be more – or fewer – hummingbirds around than they actually see. Have them write their observations in the comment section of their *Data Sheets.*

Flower Visit Protocol: This protocol allows students to learn about flowers and explore relationships between hummingbird behavior and various food sources in hummingbird habitats. In addition, students can learn about different kinds of flowers and how to maintain them.

If you have to choose between frequency of visits to feeders or flowers, there is probably more to be learned about hummingbirds by observing them feeding on natural food sources, especially native flower species. Ideally, however, your Schoolyard Hummingbird Habitat also will have at least one feeder in it, allowing for both kinds of observations.

Feeder vs. Flower Visit Protocol: This protocol builds on both the *Feeder Visit* and *Flower Visit Protocols* and offers many, many possibilities for interesting student research.

Flower Species Visit Protocol: It is not fully understood why RTHUs choose certain flower species over others, but we do know that some flower species are known to produce nectar at different rates at various times of the day. Students can work closely with scientists to better understand the relationships between feeding behavior and flower species.

Nesting Report Protocol: If your students are fortunate enough to find a hummingbird nest, please encourage them to take observations, but make sure that they do NOT disturb the hummingbirds. Students of any age will be captivated by RTHU nesting behavior and—since many details are not known—scientists will be eager to receive any student data.

Hummingbird Feeder: Care and Maintenance

If hummingbird feeders are used, fill them with a solution of 4 parts water, 1 part sugar; if hummingbirds do not drain a feeder, replace the solution TWICE each week (every third or fourth day) to eliminate mold. See www.rubythroat.org/FeedingHintsMain.html for additional information.

Helpful Hints

- Visit the Web site for *Operation RubyThroat: The Hummingbird Project* on the Web at www.rubythroat.org for more information. Each page has access to an on-line search engine that allows you or your students to type in a key word or phrase. There is also an extensive glossary of hummingbird terms that will be useful as students observe RTHUs and broaden their knowledge of birds and habitats.
- Much hummingbird activity in the U.S. occurs during Summer months when schools are not in session. Nevertheless, data collected in Spring or Autumn (including early arrival and final departure dates) are valuable. U.S. and Canadian students also may be encouraged to continue to collect data during Summer months—even if they are away from home—by using a Summer address as the reporting station. Don't forget that each new location needs a new site definition.
- Although students should try to make observations on a regular basis, we realize that circumstances sometimes interfere. The important thing is for the students to keep accurate records and to make note of when they miss observations for whatever reason.
- Personnel from Hilton Pond Center for Piedmont Natural History may be able to visit your school during the academic year to provide further instruction and possibly to band hummingbirds at your site. A limited number of host schools will be selected from those that submit data to *Operation RubyThroat: The Hummingbird Project* and The GLOBE Program.

Questions for Further Investigation

How do you think storms affect the number of RTHUs you see in your area during Spring? Summer? Autumn?

Does temperature in Spring seem to affect when RTHU nests are built and eggs laid?

Does northward migration of RTHUs in Spring appear to be more closely related to maximum, minimum, or current daily temperatures?

Is there a relationship between Spring arrival of hummingbirds and other phenological events? (See, for example, the GLOBE protocols for green-up, budburst, and lilacs.)

Does the number of RTHUs in your study area change from Spring through Autumn in the U.S. and Canada? Does the number of RTHUs in your study area change as winter progresses in Mexico and Central America? Does the mix of ages and sexes change over that time?

What environmental and ecological factors that are different in Winter make it difficult for RTHUs to stay in areas where they breed?

What can you do to improve chances that RTHUs will be attracted to your school or neighborhood?

What other questions come to mind when you observe RTHU behavior at feeders or in your Schoolyard Hummingbird Habitat?

Selected Reference Books

Howell, Steve N.G. 2002. *Hummingbirds of North America: The Photographic Guide.* AP Natural World, NY.

Johnsgard, P.A. 1997. *The Hummingbirds of North America.* Smithsonian Press, Washington DC.

Newfield, N.L. & B. Nielsen. 1996. *Hummingbird Gardens.* Chapters Publ. Ltd., Shelburne VT.

Sargent, R. 1999. *Ruby-throated Hummingbird.* Stackpole Books, Mechanicsburg PA.

Stokes, D. & L. Stokes. 2002. *Beginner's Guide to Hummingbirds. Little*, Brown, and Co., NY.

Williamson, S.L. 2001. *A Field Guide to Hummingbirds of North America.* Houghton Mifflin, NY.

Frequently Asked Questions

1. I live in the western U.S. where RTHUs don't occur. Can I still participate in *Operation RubyThroat*?

We may be able to make provisions for you to submit data, even though you will be observing different hummingbird species. You'll need to contact projects@rubythroat.org to work out specific protocols.

2. Can you tell if a hummingbird is young or an adult?

In Spring (up to mid-May) all free-flying RTHUs are adults and red-throated males are easily distinguished from white-throated females. As soon as young RTHUs start leaving the nest, ageing and sexing are more difficult because both young females and young males lack red throats. Thus, a white-throated RTHU cannot be aged or sexed reliably in the field after mid-May unless it is a young male that has developed a few red feathers or heavy green or black streaking on its throat (see photos at www.rubythroat.org/RTHUExternalMain.html).

3. Will I ever get a chance to band a hummingbird?

Students at schools near Hilton Pond Center for Piedmont Natural History in York SC may be able to schedule a bird banding field trip to the Center. In addition, Center personnel will visit a limited number of schools in the states and countries where RTHUs occur; on-site hummingbird banding may be a possibility during these visits. Schools must submit data to *Operation RubyThroat: The Hummingbird Project* and The GLOBE Program and apply to the Center to be considered for field trips or in-school visits.

4. What if RTHUs show up in Spring and then disappear?

There may be an early wave of RTHU migrants that stop for a few days at your feeder or garden and then continue flying north. It's also common in Spring even for local hummingbirds to seemingly disappear—especially females that, after mating, spend most of the day sitting on eggs or nestlings.

5. What should I look for in Autumn?

In the U.S. and southern Canada, numbers of RTHUs should increase dramatically in mid-Summer as young birds leave their nests and as early migrants from further north begin to fly back south. By mid-August, students in Mexico and central America should begin looking for the arrival of RTHUs that spent the Summer much further north.

If you have other questions, you may want to visit the Web site for *Operation RubyThroat: The Hummingbird Project* at www.rubythroat.org and type a keyword or phrase into its on-line search engine that appears on each page. The Web site contains extensive information and many photographs. If you still can't find the answer, contact the GLOBE Help Desk or send an e-mail message to projects@rubythroat.org.

Ruby-throated Hummingbird (RTHU)

Site Definition Field Guide

Task

To describe and locate the latitude, longitude, and elevation of a hummingbird site

What You Need

- ❑ *GPS Protocol Field Guide*
- ❑ *GPS Data Sheet*
- ❑ GPS receiver
- ❑ Notebook or clipboard and paper
- ❑ Pencil or pen
- ❑ Compass
- ❑ Calculator *(optional)*
- ❑ Camera
- ❑ *Hummingbird Site Definition Data Sheet*
- ❑ Wildflower identification guide *(optional if only hummingbird feeder is used)*
- ❑ Cultivated flower identification guide *(optional if only hummingbird feeder is used)*

In the Field

1. Complete the top of the *Hummingbird Site Definition Data Sheet* (Recorded By, Measurement Time, Site Name). Identify the latitude, longitude, and elevation following the *GPS Protocol Field Guide*.

2. Record the average latitude, longitude, and elevation from the *GPS Data Sheet* on the *Hummingbird Site Definition Data Sheet.*

3. Indicate if a hummingbird feeder, hummingbird nest, and/or flowers are present at site.

4. When possible, identify and list any species of flowering plants that are present.

   Note: Plant species that are actually producing blooms at any given time may change from Spring through Autumn.

5. Take a photo in each cardinal direction: North, South, East and West. Use your compass to determine the directions.

Ruby-throated Hummingbird (RTHU)

Sighting Protocol Field Guide (U.S. and Canada)

Task

To observe and record one or more of the following:

- Early arrival date of RTHUs in Spring
- Final date RTHUs are observed in Autumn
- RTHU sightings between early arrival and final sighting
- Color-marked or unusual RTHUs, or other species of hummingbirds (vagrants)

What You Need

- ❑ Pencil or pen
- ❑ Bird identification guide
- ❑ Binoculars (optional)
- ❑ *Ruby-throated Hummingbird Sighting Data Sheet*

In the Field

1. Every day about two weeks before the expected arrival of RTHUs, begin looking for RTHUs in your neighborhood and schoolyard. In most U.S. locations, the first RTHUs arrive in March and depart by early October.

   Record observation times even if hummingbirds are not seen.
2. If possible, determine sex (and age) of each RTHU that is observed.
3. Record date of first RTHU Spring sighting—including sex and age (if known)—on the *Hummingbird Sighting Data Sheet*.

   Note: In Spring through mid-May, RTHUs are easily aged and sexed; only adult males have a full red throat and only adult females have white throats.
4. In Spring, Summer, and Autumn, look for RTHUs every day. Record:
   - Each date a red-throated adult male is observed (March through October)
   - Each date an adult female is observed (white throat, March and April only)
   - Each date an undetermined sex is observed (if throat is not observed)
   - Each date an undetermined sex (adult female/young female/young male) is observed (May through October, if throat is unmarked)
   - Each date a young male is observed (May through October, if throat is heavily streaked in green or black and/or has one or more red feathers)
5. After no more RTHUs are seen, record final date of:
   - Adult male (March through November)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (adult female/young female/young male, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers)
6. In the protocols above, Observation Start Time and Observation End Time may be the same for an individual sighting.

   Note: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Feeder Visit Protocol Field Guide (U.S. and Canada)

Task

To count the number of times RTHUs visit a feeder in 45 minutes

What You Need

- ❑ Hummingbird feeder
- ❑ Food for feeder
- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Binoculars *(optional)*
- ❑ Bird identification guide
- ❑ *Ruby-throated Hummingbird Feeder Visit Data Sheet*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Feeder Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to the feeder on the *Ruby-throated Hummingbird Feeder Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male (March through October)
   - Adult female (white-throated, March and April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (adult female/young female/young male, May through October, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers

Note 1: If an individual bird comes to the feeder, departs, and immediately returns to the feeder without perching in the field of view, it counts as only one visit. If it perches within view and returns to the feeder, it still counts as one visit. Only if the bird leaves the field of view and returns can it be counted again, and then it should be counted again even if you think it may be the same bird.

Note 2: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Flower Visit Protocol Field Guide (U.S. and Canada)

Task

To count the number of times RTHUs visit flowers in 45 minutes

What You Need

- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ Schoolyard Hummingbird Habitat, flower garden or wildlife patch
- ❑ Camera (optional)
- ❑ *Ruby-throated Hummingbird Flower Visit Data Sheet*
- ❑ Binoculars (optional)

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Flower Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to flowers on the *Ruby-throated Hummingbird Flower Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male (March through October)
   - Adult female (white-throated, March and April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (adult female/young female/young male, May through October, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers

Note 1: If an individual bird enters the garden and feeds on several flowers—even different flower species—it counts as only one visit. If a bird perches within view and returns to the flowers, it still counts as one visit. Only if the bird leaves the field of view and returns can it be counted again, and then it should be counted again even if you think it may be the same bird.

Note 2: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Feeder vs. Flower Visit Protocol Field Guide

(U.S. and Canada)

Task

To count and compare the number of times RTHUs visit flowers and feeders in 45 minutes

What You Need

- ❑ Hummingbird feeder
- ❑ Fresh food mixture for hummingbird feeder
- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ Camera
- ❑ Schoolyard Hummingbird Habitat, flower garden, or wildflower patch
- ❑ Binoculars *(optional)*
- ❑ *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to the feeder and flowers on the *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male (March through October)
   - Adult female (white-throated, March and April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (adult female/young female/young male, May through October, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers

Note 1: If an individual bird enters the garden and feeds on a flower, then at a feeder, then on a flower, it counts as two flower visits and one feeder visit. Every separate visit to a flower or feeder is counted. If a bird feeds on the same flower or flower stalk several times in succession, it counts as only one flower visit. If a bird feeds on Flower A, then on Flower B, and again on Flower A, it counts as three visits. This procedure is different from the observations made when you are looking only at feeder visits or only at flower visits.

Note 2: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Flower Species Visit Protocol Field Guide (U.S. and Canada)

Task

To count the number of times RTHUs visit different flower species during 45 minutes. Observations may be continued during consecutive and/or subsequent hours to see if hummingbird flower selection changes throughout the day.)

What You Need

- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ *Ruby-throated Hummingbird Flower Species Visit Data Sheet*
- ❑ Binoculars *(optional)*
- ❑ Local wildflower and cultivated flower identification guides
- ❑ Camera *(optional)*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Flower Species Visit Data Sheet*. Record date and time period when observations are made.
2. Identify the different flower species. Record flower species on the *Ruby-throated Hummingbird Flower Species Visit Data Sheet*. If you are unable to identify the flower to species, at least take it to genus level.
3. Take a close-up photograph of any flower species that is visited by a hummingbird at your study site. Submit following the instructions in the *Implementation Guide.* This will allow verification of the identification to species.
4. For each RTHU seen during the 45 minutes, identify its sex and age if possible.
5. For each flower species, record by the following categories:
   - Red-throated adult male (March through October)
   - Adult female (white-throated, March and April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (adult female/young female/young male, May through October, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers

Note 1: When an individual bird enters a habitat, tally each time the bird feeds on a DIFFERENT flower or flower stalk for EACH species. For example, if a bird visits a Cardinal Flower stalk, then a Trumpet Creeper, and returns to the Cardinal Flower, this is two visits for Cardinal Flower and one for Trumpet Creeper. If it feeds from the same flower or flower stalk several times in succession, it counts as only one visit.

Note 2: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Nesting Report Protocol Field Guide (U.S. and Canada)

Task

To observe and report nesting behavior of RTHUs

What You Need

- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ *Ruby-throated Hummingbird Nesting Data Sheet*
- ❑ Binoculars *(optional)*
- ❑ Camera

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Nesting Data Sheet*. Record when the nest was found.
2. Record the dates for what you can of the following observations. **Do not disturb the nest.**
   - Start of nest construction
   - End of nest construction
   - Laying of first egg
   - Laying of second egg
   - First sighting of adult female sitting on nest
   - Hatching date(s) for egg(s)
   - First sighting of young hummingbirds (nestlings) in nest
   - Fledging date (when nestlings leave the nest)
   - Last sighting of adult female on nest
3. Record if the eggs do not hatch or if the nestlings die. If the female rebuilds the nest or reuses the nest for a new set of eggs, fill out a second data sheet and record the new observations as listed above.
4. Record dates and observations of any adult male behavior at the nest. Be careful to report observations of what you actually see, rather than an interpretation of what you see.

Examples: 2 April 2002—Male sitting on nest for 30 seconds (NOT male incubating eggs)
1 May 2002—Male flying over nest (NOT male protecting nest)

Note 1: It is against state or federal law to possess the body, feathers, skeleton, nest or eggs of any wild free-flying bird—including hummingbirds—unless you have a special permit.

Note 2: If you see a color-marked or unusual RTHU, other species of hummingbirds (vagrants), or ANY hummingbird from mid-October through mid-March, describe the color markings and shape of beak. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Sighting Protocol Field Guide

(for Mexico, Central America, and Caribbean)

Task

To observe and record one or more of the following:

- Early arrival date of RTHUs in Autumn
- Final date RTHUs are observed in Spring
- RTHU presence between early arrival and final sighting
- RTHUs that are color-marked or with unusual plumage

What You Need

- ❑ Pencil or pen
- ❑ Bird identification guide
- ❑ *Ruby-throated Hummingbird Sighting Data Sheet*
- ❑ Binoculars *(optional)*

In the Field

1. Every day about two weeks before the expected arrival of RTHUs, begin looking for RTHUs in your neighborhood and schoolyard. In Mexico, the first RTHUs probably arrive in early to-mid August and begin departing by late February or early March. Precise early arrival and final departure dates for Mexico, Central America, and the Caribbean are not known, so please be alert for RTHUs from August through April, perhaps even through mid-May. *Record observation times even if hummingbirds are not seen.*
2. If possible, determine sex and age of each RTHU that is observed.
3. Record date of first RTHU Autumn sighting—including sex and age (if known)—on the *Hummingbird Sighting Data Sheet*. **Note:** January through mid-May, RTHUs are easily aged and sexed; only adult males have full red throats and only females have completely white throats; a few males that hatched very late the preceding summer may have incomplete red throats.
4. In Autumn, Winter, and Spring, look for RTHUs every day. Record:
   - Each date a red-throated adult male is observed
   - Each date an adult female is observed (white throat, January through mid-May only)
   - Each date an undetermined sex is observed (if throat is not observed)
   - Each date an undetermined sex (possible adult female/young female/young male) is observed (August through December, if throat is unmarked)
   - Each date a young male is observed (August through December, and perhaps later, if throat is heavily streaked in green or black and/or has one or more red feathers)
5. After no more RTHUs are seen, record final date of:
   - Adult male
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (possible adult female/young female/young male, through December, if throat is unmarked)

- Young male (if throat is heavily streaked in green or black and/or has one or more red feathers)

6. In the protocols above, Observation Start Time and Observation End Time may be the same for an individual sighting.

Note: If you see a color-marked RTHU, describe the color markings and attempt to observe whether the bird is banded and on which leg. If you see a RTHU with unusual colors (albinism, leucism, etc.) make note of the colors and patterns and get a photo if possible. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Feeder Visit Protocol Field Guide

(for Mexico, Central America, and Caribbean)

Task

To count the number of times RTHUs visit a feeder in 45 minutes

What You Need

- ❑ Hummingbird feeder
- ❑ Food for feeder (fresh sugar water mix)
- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ *Ruby-throated Hummingbird Feeder Visit Data Sheet*
- ❑ Binoculars *(optional)*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Feeder Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to the feeder on the *Ruby-throated Hummingbird Feeder Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male
   - Adult female (white-throated, January through April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (possible adult female/young female/young male, August through December, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers; nearly all develop a full red throat sometime before departing north in spring)

Note 1: If an individual bird comes to the feeder, departs, and immediately returns to the feeder without perching in the field of view, it counts as only one visit. If it perches within view and returns to the feeder, it still counts as one visit. Only if the bird leaves the field of view and returns can it be counted again, and then it should be counted again even if you think it may be the same bird.

Note 2: If you see a color-marked RTHU, describe the color markings and attempt to observe whether the bird is banded and on which leg. If you see a RTHU with unusual colors (albinism, leucism, etc.) make note of the colors and patterns and get a photo if possible. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Flower Visit Protocol Field Guide

(for Mexico, Central America, and Caribbean)

Task

To count the number of times RTHUs visit flowers in 45 minutes

What You Need

- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ Schoolyard Hummingbird Habitat, flower garden, or wildflower patch
- ❑ *Ruby-throated Hummingbird Flower Visit Data Sheet*
- ❑ Camera *(optional)*
- ❑ Binoculars *(optional)*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Flower Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to flowers on the *Ruby-throated Hummingbird Flower Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male
   - Adult female (white-throated, January through April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (possible adult female/young female/young male, August through December, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers; nearly all develop a full red throat sometime before departing north in spring)

Note 1: If an individual bird enters the garden and feeds on several flowers—even different flower species—it counts as only one visit. If a bird perches within view and returns to the flowers, it still counts as one visit. Only if the bird leaves the field of view and returns can it be counted again, and then it should be counted again even if you think it may be the same bird.

Note 2: If you see a color-marked RTHU, describe the color markings and attempt to observe whether the bird is banded and on which leg. If you see a RTHU with unusual colors (albinism, leucism, etc.) make note of the colors and patterns and get a photo if possible. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Feeder vs. Flower Visit Protocol Field Guide

(for Mexico, Central America, and Caribbean)

Task

To count and compare the number of times RTHUs visit flowers and feeders in 45 minutes

What You Need

- ❑ Hummingbird feeder
- ❑ Food for feeder (fresh sugar water mix)
- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ Schoolyard Hummingbird Habitat, flower garden, or wildflower patch
- ❑ *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet*
- ❑ Camera (optional)
- ❑ Binoculars (optional)

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet*. Record date and time period that observations are made.
2. For each RTHU seen, identify its sex and age if possible.
3. Record each visit to the feeder and flowers on the *Ruby-throated Hummingbird Feeder Vs. Flower Visit Data Sheet* during the 45 minutes. Record by the following categories:
   - Red-throated adult male
   - Adult female (white-throated, January through April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (possible adult female/young female/young male, August through December, if throat is unmarked)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers; nearly all develop a full red throat sometime before departing north in spring)

Note 1: If an individual bird enters the garden and feeds on a flower, then at a feeder, then on a flower, it counts as two flower visits and one feeder visit. Every separate visit to a flower or feeder is counted. If a bird feeds on the same flower or flower stalk several times in succession, it counts as only one flower visit. If a bird feeds on Flower A, then on Flower B, and again on Flower A, it counts as three visits. This procedure is different from the observations made when you are looking only at feeder visits or only at flower visits.

Note 2: If you see a color-marked RTHU, describe the color markings and attempt to observe whether the bird is banded and on which leg. If you see a RTHU with unusual colors (albinism, leucism, etc.) make note of the colors and patterns and get a photo if possible. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Ruby-throated Hummingbird (RTHU)

Flower Species Visit Protocol Field Guide

(for Mexico, Central America, and Caribbean)

Task

To count the number of times RTHUs visit different flower species during 45 minutes. Observations may be continued during consecutive and/or subsequent hours to see if hummingbird flower selection changes throughout the day.)

What You Need

- ❑ Pencil or pen
- ❑ Clipboard
- ❑ Bird identification guide
- ❑ Local wildflower and cultivated flower identification guides
- ❑ Schoolyard Hummingbird Habitat, flower garden, or wildflower patch
- ❑ *Ruby-throated Hummingbird Flower Species Visit Data Sheet*
- ❑ Camera *(optional)*
- ❑ Binoculars *(optional)*

In the Field

1. Fill out the top of the *Ruby-throated Hummingbird Flower Species Visit Data Sheet*. Record date and time period when observations are made.
2. Identify the different flower species at site. Record flower species on the *Ruby-throated Hummingbird Flower Species Visit Data Sheet*. If you are unable to identify the flower to species, at least take it to genus level.
3. Submit a close-up photograph of any flower species that is visited by a hummingbird on your study site. This will allow verification of the identification to species.
4. For each RTHU seen during the 45 minutes, identify its sex and age if possible.
5. For each flower species, record by the following categories:
   - Red-throated adult male
   - Adult female (white-throated, January through April only)
   - Undetermined sex (if throat is not observed)
   - Undetermined sex (possible adult female/young female/young male, August through December, if throat is white)
   - Young male (if throat is heavily streaked in green or black and/or has one or more red feathers; nearly all develop a full red throat sometime before departing north in spring)

Note 1: When an individual bird enters a habitat, tally each time the bird feeds on a DIFFERENT flower or flower stalk for EACH species. For example, if a bird visits a Cardinal Flower stalk, then a Trumpet Creeper, and returns to the Cardinal Flower, this is two visits for Cardinal Flower and one for Trumpet Creeper. If it feeds from the same flower or flower stalk several times in succession, it counts as only one visit.

Note 2: If you see a color-marked RTHU, describe the color markings and attempt to observe whether the bird is banded and on which leg. If you see a RTHU with unusual colors (albinism, leucism, etc.) make note of the colors and patterns and get a photo if possible. Record your observations on the *Ruby-throated Hummingbird Sighting Data Sheet.* Contact Hilton Pond Center for Piedmont Natural History at research@hiltonpond.org or (803) 684-5852 as soon as possible.

Phenological Gardens

Purpose

To observe the flowering and leaf stages of selected garden plants throughout the year

Overview

After a phenological garden is planted, students observe the growth of leaves and blooming of flowers on the plants. These plants were selected because each plant blooms at a different time in the year.

Student Outcomes

Students will learn how to identify the different flowering stages during plant growth. Students will make connections between climate and plant blooming.

Science Concepts

Earth and Space Sciences

Soils have properties of color, texture and composition; they support the growth of many kinds of plants.

Weather can be described by measurable quantities.

Weather changes from day to day.

Weather changes over the seasons.

Soil consists of weathered rocks and decomposed organic matter.

Water circulates through the biosphere, lithosphere, atmosphere and hydrosphere (water cycle).

The sun is the major source of energy for the growth of plants.

Life Sciences

Plants have basic needs (water, sunlight, food, etc.).

The behavior of plants is influenced by external cues.

Plants have life cycles.

Plants closely resemble their parents.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Geography

Plants help to define the character and spatial distribution of ecosystems on the Earth's surface.

Scientific Inquiry Abilities

Identifying plant phenophases.

Identifying shrub species.

Planting and caring for shrubs.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Materials and Tools

For Site Definition (once only):

Camera

GPS receiver

Compass

Tape measure

Markers to label plants

Pencil or pen

Paper to draw map

Soil equipment for measuring pH

Phenological Garden Site Definition Field Guide

Phenological Garden Site Definition Sheet

Basic GPS Protocol Field Guide

Basic GPS Protocol Data Sheet

Soil Characterization Field Measurement Protocol

Soil Characterization Lab Analysis Protocol

For Observations

Pencil or pen

Phenological Garden Data Sheet

Phenological Garden Field Guide

For Planting and Care

Pail

Bone meal or superphosphate

Fertilizer or compost

Peat moss (for heather)

Wooden or metal stakes

Flagging tape

Level

All

Frequency

Once a day for each plant variety shortly before leaf growth and blooming starts and during the blooming stages. In between blooms, two or three times a week.

Preparation

Familiarity with the different leaf and flowering stages of the plants to be observed in the garden

Prerequisites

None

Phenological Gardens - Introduction

Plants respond to the environment around them. Green plants grow when there is enough sunlight, warmth, moisture, and nutrients. They respond to the temperature and moisture of the air and soil around them. During dry or cold seasons, there is little or no growth. When the conditions are right, such as warmer temperature, more moisture and longer lengths of day, plants start growing and reproducing.

Plants also change the environment around them. They take carbon dioxide from the atmosphere, incorporate the carbon in their leaves and stems, and give off oxygen. They also take moisture and nutrients from the soil and produce new growth. In the process, many chemicals are produced and some of these, along with water vapor, are released into the atmosphere. To know how large an effect plants are having, scientists need to know the length and characteristics of the growing season.

This protocol asks you to observe the flowering of different plants. The plant varieties were chosen because they flower at different times during the year. This allows you and scientists to learn how the growing season is changing from year to year as well as see if there is an overall change in the growing season over a longer length of time. The collection of atmosphere data (such as temperature and precipitation) and soil moisture and temperature data will greatly help you and scientists interpret the phenological garden data.

These plants were also chosen because plants of the same species are genetically identical. That means they respond the same to changes in temperature and moisture and other factors that affect their flowering and growth. Therefore variations observed in the dates of growth stage events can be clearly linked to climate rather than to variations among plants.

How Scientists Use Your Data

The plants selected for your garden are part of a scientific phenological network called Global Phenological Monitoring (GPM) Program (www.student.wau.nl/~arnold/gpmn.html) Scientists in GPM Program study how the different species respond to changes in climate. The GPM data may be compared with the flowering of ornamental shrubs in your garden to help find relationships among the flowering dates of ornamental shrubs and those of fruit trees. Thus your phenological data are also indicators of the flowering dates of fruit trees and may be linked to the management of agricultural and horticultural practices.

Teacher Support

Which Plants You Will Observe and How to Get Them

A GLOBE phenological garden contains a variety of plants that bloom at different times during the year. The plants listed in Table EA-PG-2 are: Witch-hazel (*Hamamelis x intermedia* 'Jelena' and'*Hamamelis virginiana* 'Genuine'), Snowdrops (*Galanthus nivalis* 'Genuine'), Forsythia (*Forsythia suspensa* 'Fortunei'), Lilac (*Syringa x chinensis* 'Red Rothomagensis'), Mock-orange (*Philadelphus coronarius* 'Genuine'), and Heather (*Calluna vulgaris* 'Allegro' and 'Long White').

The plants need to come from selected nurseries to make sure that the plants are clones. Clonal plants are needed to make large-scale comparison among the dates of the different developmental phases of the plant. Vegetative propagated plants are cloned plants and they are used to avoid the hereditary variability of plants. Right now, we are establishing nurseries in Beijing and in the United States.

Not all of the plants may grow where you live. So select the ones that do. However, if all the plants can grow where you live, the whole phenological garden is requested.

Measurement Procedures

These plants bloom throughout the year. When one of the plant species is about to bloom, observations should be made every day until all the flowering and leaf stages (phenophases) are recorded. If no plants are blooming and leaves are not growing, observations can be made two or three times a week.

You can select a convenient time during the day to observe the plants. It is preferred that students observe at the same time each day.

The observations of the different phases are carried out on each plant. If a plant dies continue observing the other species and request new plants from the tree nursery. If the plant dies because the climate is not suitable for the plant at the site, do not plant the same species again because it would die again. Keep on observing the other plants.

Phenophases to Observe

It is very important to observe the dates of the phenophases following the definitions below.

Use the pictures of the phenophases included in the protocol to teach students how to correctly identify the growth stages on their shrubs.

BF = Beginning of flowering: This phase occurs when at least 3 places on the plant the first flowers have opened completely.

Witch Hazel (*Hamamelis x Intermedia 'Jelena', Hamamelis virginiana 'genuine'*): Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

Lilac (*Syringa x chinensis 'Red Rothomagensis'*): Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

Mock-orange (*Philadelphus coronaries 'genuine'*): Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

Forsythia (*Forsythia suspense*), and Heather (*Calluna vulgaris*): Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

Heather (*Calluna vulgaris*): Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

Snowdrops (*Galanthus nivalis*): The flower is considered open only when the outer leaves have spread and the stamens are visible.

GF = General flowering: This phase occurs when approximately 50% of the flowers are open.

EF = End of flowering: This phase occurs when about 95% of all flowers have died or fallen off.

Additionally for lilac and forsythia, observe:

LU = Beginning of leaf unfolding: The first regular surfaces of leaves become visible in about 3 places on the observed plant. The first leaf of a plant has pushed out of the bud up to its leaf stalk.

FL = Full leafs: This phase occurs when about 95% of all leaves are unfolded.

Connections to Other Measurements

Before you plant your garden, you could either dig a soil pit or collect a soil profile with an auger and perform a soil characterization following the *Soil Characterization Field Measurement Protocol* in the *Soil Chapter*. If the soil profile has been affected by previous plantings, or the addition of water and fertilizer, please mention this in the comment section on the *Soil Characterization Data Sheet*.

Measurements of air and soil temperature, soil moisture, and precipitation could lead to very interesting student research projects exploring relationships between atmosphere and soil measurements, and plant phenology.

Site Selection

Choose a site that represents the natural soil and climate of the region. Use the following guidelines to help you select a site. We realize that you may not be able to locate an "ideal" site. Do the best you can and record any deviations from the ideal in the comment (metadata) section on your *Phenological Garden Site Definition Data Shee*t.

If you think the potential site may not represent the climate of the region, contact GLOBE.

Find a location to plant your shrubs with the following specifications:

- An un-shaded place that is away from buildings, trees, or other obstacles. The minimum distance from the base of any obstacle should be at least 1.5 times the height of that obstacle.
- Away from footpaths, sidewalks, and roads. The distance from a two-lane road

should be at least 8 meters. The distance from a large eight-land highway should be at least 25 meters.
- Easily accessible.
- Where there is no risk of plants being trampled by people or animals.
- Where excessive amounts of snow do not accumulate from drifting or plowing.
- On a level surface. If you have a hilly landscape, avoid if possible, the low areas that can unduly delay shrub development in the Spring. Avoid places with slopes greater than 3 degrees.
- In soil commonly found in your area. Avoid planting in soil, such as a garden, that has received heavy applications of manure or compost.
- Where there are no special microclimates (such as frost pockets or windy slopes) for plants.
- Avoid places with lots of artificial light.

The plants do not have to be planted in any specified arrangement. Table EA-PG-2 provides guidelines for minimum distances between plants. Larger distances are desirable.

Planting and Care

1. Planting

The best time to establish the phenological garden is in spring or autumn. If you plant the garden in the autumn, you have to wait until the spring after the next to start your observations.

Materials

❑ Pail

❑ Bone meal or superphosphate

❑ Fertilizer or compost

❑ Peat moss (only for heather)

❑ Wooden or metal stakes

❑ Flagging tape

Note: The quality and validity of data depend strongly upon healthy shrubs, so you should observe the following practices to ensure their health. You may want to consult a horticulturist.

1. As soon as you get the plants, soak the roots in a pail of water for a few hours.
2. Dig holes deep enough to just cover the roots and wide enough you can spread roots horizontally. Leave the minimum distance between plants shown in Table EA-PG-2.
3. Mix about 120 ml of bone meal or superphosphate into the soil in which the plant is going to be planted. In heavy clay soils or in very sand soils, add equal parts of compost to backfill soil to improve growing conditions. Heather likes to grow in weak acid soils (pH 5-6). For this reason add peat moss to the soil if you are planting heather.
4. At least once a week for the first month, water the new transplants until the soil is soaked.
5. Apply either a dry fertilizer such as 10-10-10 or a liquid soluble one during the first growing season according to label directions.
6. Place a wooden or metal stake beside each plant to indicate its location and prevent accidental damage.
7. Mark each shrub with flagging tape or some other durable identification. Label the flagging tape with the name of the plant variety for each shrub.

Table EA-PG-2: Guidelines for Minimum Distances for Plants in a Garden.

Common Name	Scientific Name and Variety	Minimum Distance (m)
Witch Hazel	*Hamamelis x intermedia* 'Jelena'	2.5
Snowdrops	*Galanthus nivalis* 'Genuine'	0.05 - 0.1 depth: 0.05-0.10
Forsythia	*Forsythia suspensa* 'Fortunei'	1.5
Lilac	*Syringa x chinensis* 'Red Rothomagensis'	2.5
Mock-orange	*Philadelphus coronarius* 'Genuine'	3.0
Heather	*Calluna vulgaris* 'Allegro'	0.5
Heather	*Calluna vulgaris* 'Long White'	0.5
Witch hazel	*Hamamelis virginiana* 'Genuine'	2.5

2. Annual Care

Materials

- ❑ 5-10-10 fertilizer or its equivalent
- ❑ Mulch: peat moss, bark, well-rotted sawdust or similar organic matter

1. Spread 50 g of 5-10-10 fertilizer or its equivalent evenly around each plant. Shrub fertilizer stakes may be used instead.
2. Keep the soil within 30 cm of the base of each plant free of grass and weeds with a mulch of peat moss, bark, well-rotted sawdust, wood chips, or similar organic material.
3. During a long dry period, you may have to water the plants.
4. During the first and second years, the plants may need extra care to make sure that they are strong. After that, fertilizers may not be needed. Check periodically to make sure that they are in good health.

3. Pruning

Heather should be pruned once a year in the beginning of spring (in March or April, depending on weather). You can cut the upper half of the plant.

Prune lilacs immediately after bloom in spring because the following year flower buds are formed on new wood that grows after bloom. Avoid fall pruning because it will destroy the buds for the next year. Old, dried-up flowers may be cut off if desired so that the shrubs do not look unsightly.

All other shrubs should be pruned every 5-10 years to maintain good shape.

One or more of the older main stems at the base of the plant may be removed and some, or all, of the remaining stems trimmed back to maintain the size and shape desired. Never remove more than 1/3 of the plant at any one time.

4. Protection Against Disease, Pests, and Severe Weather

These plants are relatively resistant to insects and diseases. Occasionally they may be affected by powdery mildew, leaf spot, scale, or aphids. Control measures rarely are needed except for scales. Should these diseases or insects become serious, regular applications of a pesticide may be necessary. Contact the Agricultural Extension Service in your state, province or county for the latest control recommendations.

In some locations animals, such as rabbits and mice, may severely damage the plants. Wire-mesh guards around the base of the plants help to control such damage.

For winter protection in areas of little snowfall, 5-10 cm (2-4 inches) of mulch around the base of each plant will protect its roots from frost damage. To prevent breakage from ice, wrap stems together loosely with twine or place burlap (such as from a feed bag) on a frame over the plant. Do not use plastic.

Questions For Further Investigation

How does a year with more precipitation than usual affect when the different phenophases occur?

Which has more influence on when the phenophases occur: soil temperature or air temperature?

Does elevation affect when phenophases occur? If so, how?

Are there differences when phenophases occur between coastal and continental areas?

Frequently Asked Questions

1. Should we observe other vegetation in the local region?
For the phenology protocol, please only observe the plants in your phenology garden. But you can also observe the other vegetation in your local region in order to compare the phenophases of the indicator plants in your phenology garden with the natural vegetation in your surrounding.

2. Are these plants invasive?
No.

3. How do these plants pollinate?
All plants in the phenological garden are insect-pollinated. They bloom in different colors to attract the insects. The male and female parts of the plant are in each flower.

4. How does the nature of the soil affect the timing of flowering?
The timing of phenological events is mainly driven by temperature. However, soil characteristics can influence the heating of atmosphere. Soil moisture also can influence the timing of phenophases.

Phenological Gardens

Site Definition Field Guide

Task

To draw a map, take photographs, describe the soil, and locate the latitude, longitude, and elevation of your phenological garden site

What You Need

- ❑ GPS receiver
- ❑ *Basic GPS Field Guide*
- ❑ *GPS Data Sheet*
- ❑ Compass
- ❑ *Phenological Garden Site Definition Sheet*
- ❑ Camera
- ❑ Tape measure or meter stick
- ❑ Paper to draw map
- ❑ Pencil or pen
- ❑ Markers
- ❑ *Soil Characterization Field Measurement Protocol*
- ❑ *Soil Characterization Lab Analysis Protocol*
- ❑ Soil equipment for measuring pH (refer to protocol)

In the Field

1. After the garden is planted, draw a map of the garden showing the locations of each plant. Include on the map:

   -School name and address.

   -Date

   -Directions: North, East, South, West.

   -Distances between plants in meters
2. Label each plant with a marker.
3. Identify the latitude, longitude, and elevation following the *Basic GPS Measurement Protocol*.
4. Stand in the middle of the garden and take photographs in the North, East, South, West directions. Use the compass to determine the directions.
5. Take a photograph of the garden.
6. Identify the soil texture in the top 10 cm following *Soil Characterization Field Measurement Protocol*.
7. Measure the pH of the top 10 cm of soil following *Soil Characterization Lab Analysis Protocol.*
8. Submit map and photos to GLOBE by mailing to the address given in the *Implementation Guide* in the GLOBE *Teacher's Guide*.

Phenological Gardens

Field Guide

Task

To record when the phenophases occur for each shrub in your phenology garden

What You Need

- ❑ *Phenological Garden Data Sheet*
- ❑ Tape measure or meter stick
- ❑ Pencil or pen

In the Field

1. Examine each shrub.
2. For each shrub, record the dates of the three phenophases. Keep separate records of these dates for each shrub. The three phenophases in order are:

   BF = Beginning of flowering: This phase occurs when at least 3 places on the plant the first flowers have opened completely.

   Witch Hazel *(Hamamelis x Intermedia 'Jelena', Hamamelis virginiana 'genuine')*: Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

   Lilac *(Syringa x chinensis 'Red Rothomagensis')*: Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

   Mock-orange *(Philadelphus coronaries 'genuine')*: Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

   Forsythia *(Forsythia suspense)*, and Heather *(Calluna vulgaris)*: Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

   Heather *(Calluna vulgaris)*: Only look to see if the flowers have opened. It is not necessary to see pollen falling off the stamens.

   Snowdrops *(Galanthus nivalis)*: The flower is considered open only when the outer leaves have spread and the stamens are visible.

   GF = General flowering: This phase occurs when more than 50% of the flowers are open.

   EF = End of flowering This phase occurs when about 95% of all flowers have died or fallen off.

Additionally for lilacs and forsythia:

   LU = Beginning of leaf unfolding: The first regular surfaces of leaves become visible in about 3 on the observed plant. The first leaf of a plant has pushed out of the bud up to its leaf stalk.

   FL = Full leafs: This phase occurs when about 95% of all leaves are unfolded.

3. In the autumn, measure the height of each plant except snowdrops. This is done once a year only.
4. If plants are watered or pruned, record each date.
5. If fertilizer is used, record date of application and type of fertilizer.

Note: It is important to report if a plant appears to be in poor health

Phenological Gardens

Site Definition Data Sheet

School Name: ________________________________Class or Group Name:_______________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: ___________________________

Site name (give your site a unique name):____

Coordinates: Latitude: _____________________ ❒ N or ❒ S (check one)
Longitude: _____________________ ❒ E or ❒ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❒ GPS ❒ Other

If other, describe:____

Nearest Atmosphere Site: ATM-______

Distance to ATM Site: ____ meters;
Direction to Site: ❒ N ❒ NE ❒ E ❒ SE ❒ S ❒ SW ❒ W ❒ NW

Elevation Difference (Atmosphere Site – this site):_______ meters (this value may be positive or negative)

Nearest Soil Moisture Site: SMS-_____

Distance to Soil Moisture Site:______(meters);
Direction to Site: ❑ N ❑ NE ❑ E ❑ SE ❑ S ❑ SW ❑ W ❑ NW

Elevation Difference (Atmosphere Site – this site):_______ meters (this value may be positive or negative)

Plants in Garden

Shrub	Planted in Garden? Yes or No	Date planted
Witch Hazel 'Jelena'		
Witch Hazel 'Genuine'		
Lilac		
Mock-Orange		
Forsythia		
Heather 'Allegro'		
Heather 'Long White'		
Snowdrops		

Soil Texture in the top 10 cm (from *Soil Characterization Field Measurement Protocol*): ____________

Soil pH in the top 10 cm (from *Soil Characterization Lab Analysis Protocol*): ______________________

Soil pH method (check one): ❑ paper ❑ meter

Photo Number and Orientation

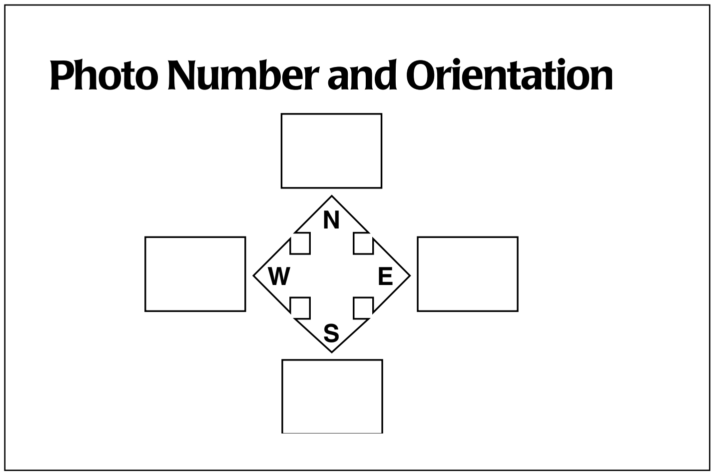


Photo of Garden

Comments (Metadata): ____

____

____

____

____

____

____

____

____

Phenological Gardens
Data Sheet

School Name: ____________________Class or Group Name:__________________________________

Name(s) of student(s) filling in Data Sheet:____

____

Site Name:____

For witch hazel, mock-orange, heather and snowdrops, record the dates for the following flowering stages:

	Flowering Stage		
Shrub	**BF**	**GF**	**EF**
Witch Hazel 'Jelena'			
Snowdrops			
Mock-Orange			
Heather 'Allegro'			
Heather 'Long White'			
Witch Hazel 'Genuine'			

BF = Beginning of flowering

GF = General flowering

EF = End of flowering

For lilac and forsythia, record the dates for the following flowering and leaf growth stages:

	Flowering Stage			Leaf Stage	
Shrub	**BF**	**GF**	**EF**	**LU**	**FL**
Lilac					
Forsythia					

LU = Beginning of leaf unfolding

FL = Full leafs

Height and health of each plant. Measure in the Autumn.

Shrub	**Height (cm)**	**Health of Shrub** **Healthy = H** **Unhealthy = U** **Dead = D**	**If shrub died, did you replace it with another shrub? (yes or no)**
Witch Hazel 'Jelena'			
Snowdrops	not necessary to measure the height		
Mock-Orange			
Heather 'Allegro'			
Heather 'LongWhite'			
Lilac			
Forsythia			

Was fertilizer used on the plants this year?________ If yes, date of application: ________________

Type of fertilizer ____________________

Record dates plant(s) were watered:____________________

If plants are pruned, record date(s):____________________

Comments (Metadata): ____

____

____

____

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____

____

____

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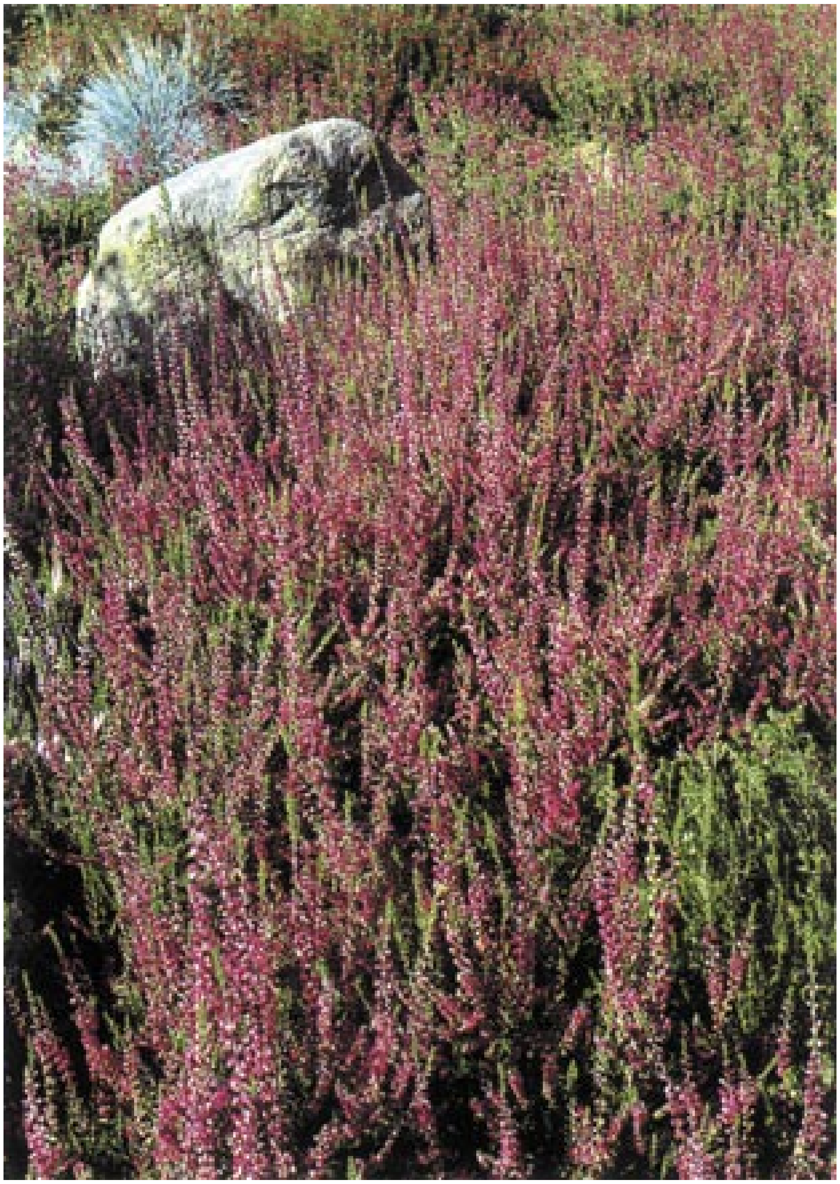


Clonal and Common and Lilac Protocol

Purpose

Record the five phenophases of either common or clonal lilac plants.

Overview

During the growing season, students will observe their lilac plants and identify the five phenophases (first leaf, full or 95% leafed, first bloom, full bloom and end of bloom) for each lilac plant.

Student Outcomes

Students will learn to,

- Identify the five phenophases of lilac plant;
- Examine relationships between weather and climate, and when the phenophases occur;
- Communicate with other GLOBE schools;
- Collaborate with other GLOBE schools;
- Share observations by submitting data to GLOBE archive.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Life Sciences

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Plants and animals have life cycles.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

5-10 minutes

Frequency

Once a day preferably at the same time each day, starting in early spring to the end of bloom

Materials and Tools

For Site Definition (once only)

- *GPS Field Guide*
- *GPS Data Sheet*
- GPS
- Compass
- Camera

For Observations

- *Clonal and Common Lilac Site Field Guide*
- *Clonal and Common Lilac Site Definition Sheet*
- *Clonal and Common Lilac Field Guide*
- *Clonal and Common Lilac Data Sheet*
- Pencil or pen

For Planting and Care

- Pail
- Bone meal or superphosphate
- Fertilizer
- Peat moss or compost
- Wooden or metal stakes
- Flagging tape

Preparation	**Prerequisites**
Make copies of *Data Sheets* Make color copies of color photographs of the 5 phenophases (if color copier is available)	Practice identifying phenophases of lilac plants

Introduction

The *Common and Clonal Lilac Protocol* asks students to examine one or two species of plants– lilacs (*Syringa vulgaris and S. chinensis*). *Budburst, Green-up and Green-down Protocols*, on the other hand, ask students to observe native vegetation in their area. In places where lilacs grow, students can observe the budding and blooming of common lilac plants. There may be plants already growing at or nearby your school, or a lilac plant can be bought and planted for students to observe. Clonal plants *(Syringa chinensis)* are genetically identical individuals. Cloned plants are available in limited supply each year. GLOBE schools can apply to receive a pair of cloned lilac plants.

Plants of the same species respond similarly to environmental changes, such as changes in temperature and moisture, even if they are located in different regions in the world. By having a network of lilac plants around the world (where this plant species is capable of growing), scientists can then examine regional and global patterns in phenology. Clonal plants respond identically to environmental changes. Variations observed in the dates of growth stage events in clonal plants can be clearly linked to climate rather than to variations between individual plants.

Scientists will use on-the-ground observations of native trees to refine the interpretation of satellite data. Scientists are interested in learning how native vegetation responds from year-to-year and over many, many years. Clonal and common lilac observations serve as vital links between satellite measurements and native plant phenology in local areas. Phenology data will improve models of Earth systems and understanding of global climate change. Lilac and native tree phenology observations are easy and inexpensive and are a wonderful way to learn about interactions between plants and the atmosphere and soil.

Teacher Support

How to obtain common or clonal lilac plants

Common lilacs can be bought at a local garden center. Please make sure you buy lilac plants with the scientific name *Syringa vulgaris*. They are often called 'old-fashioned' or 'hedge' lilacs. Only grow lilacs if the local climate can support them. Do not perform the protocol in areas where continued watering is required for lilacs to survive. If you have any questions about the lilac's ability to thrive "naturally" in your region, please consult a local horticulture specialist.

Cloned plants are available in limited supply each year. GLOBE schools can apply to receive a pair of cloned lilac plants. Up to twenty-five GLOBE schools will be selected each year and given two clonal lilac plants. Selection will be made from geographically diverse areas where the lilacs are likely to grow successfully. Preference will be given to schools making the GLOBE Chief Scientist's Atmosphere Honor Roll. To be eligible, the school must commit to participate in this special project for a minimum of five years and also must plant and observe at least two common lilac plants. The common and clonal lilacs must be planted next to one another so that they will experience the same climate conditions.

To apply for cloned lilac plants, please send your GLOBE School name, mailing address, GPS coordinates and a written statement of commitment to participate in this research for five years from the school principal or other appropriate authority to Prof. Schwartz (email: mds@uwm.edu or Fax: (414) 229-3981).

Advance Preparation

Use the pictures of the five phenophases to teach students how to correctly identify the growth stages on their lilac shrubs.

Measurement Procedures

When to Start Observations:

In the middle of winter, lilac buds are desiccated (dried out) and appear somewhat 'shriveled' (winter buds closed).

In late winter, after conditions begin to warm, the buds hydrate (swell due to becoming moist) and the tips open slightly (winter buds open).

Watching for these two events is the best way to know when to start daily observations looking for first leaf. Once the buds have swelled and bud ends are slightly open and a bit green, the next round of warm weather can force the first leaf event.

Phenophases of the Lilac Shrub:

1. **First leaf** is when the widest part of the newly emerging leaf has grown beyond the ends of its opening winter bud scales. The leaf is distinguished by its prominent midrib and veins

2. **Full or 95% leafed** is when nearly all (at least 95%) of the actively growing leaf buds have already leafed

3. **First bloom** is when at least 50% of the flower clusters have at least one open flower. The lilac flower cluster is a grouping of many, small individual flowers.

4. **Full bloom** is when 95% of the flower clusters no longer have any unopened flowers but before many of the flowers have withered

5. **End of bloom** is when at least 95% of the flowers have withered or dried up and the floral display has ended.

Connections to Other Measurements

Before you plant your lilacs, you could either dig a soil pit or collect a soil profile with an auger and perform a soil characterization following the *Soil Characterization Field Measurement Protocol* in the *Soil Chapter*. If the soil profile has been affected by previous plantings, or the addition of water and fertilizer, please mention this in the comment section on the *Soil Characterization Data Sheet*.

Measurements of air and soil temperature, soil moisture, and precipitation could lead to very interesting student research projects exploring relationships between atmosphere and soil measurements, and plant phenology.

Site Selection

Choose a site that represents the natural soil and climate of the region. Use the following guidelines to help you select a site. We realize that you may not be able to locate an "ideal" site. Do the best you can and record any deviations from the ideal in the comment (metadata) section on your *Common and Clonal Lilac Site Definition Shee*t.

Find a location to plant your shrubs with the following specifications:

- An unshaded place that is away from buildings, trees, or other obstacles. The minimum distance from the base of any obstacle should be at least 2 times the height of that obstacle.
- Away from footpaths, sidewalks, and roads. The distance from a two-lane road should be at least 8 meters. The distance from a large eight-land highway should be at least 25 meters.
- Easily accessible.
- Where there is no risk of plants being trampled by people or animals.
- Where excessive amounts of snow do not accumulate from drifting or plowing.
- On a level surface. If you have a hilly landscape, avoid if possible, the low areas that can unduly delay shrub development in the Spring. Avoid places with slopes greater than 3 degrees.
- In soil commonly found in your area. Avoid planting in soil, such as a garden, that has received heavy applications of manure or compost.
- Where there are no special microclimates (such as frost pockets or windy slopes) for plants.
- Avoid places with lots of artificial light.

Planting and Care

1. Planting

Lilac shrubs can be planted as soon as the ground is warm in the spring and on into the summer, provided there is at least a month of warm weather to bring out leaves before the cold season. Late spring, early summer planting is best.

Materials

- ❑ Pail
- ❑ Bone meal or superphosphate
- ❑ Fertilizer
- ❑ Peat moss or compost
- ❑ Wooden or metal stakes
- ❑ Flagging tape

Note: The quality and validity of data depend strongly upon healthy shrubs, so you should observe the following practices to ensure their health. You may want to consult a horticulturist.

1. As soon as you get the plants, soak the roots in a pail of water for a few hours.
2. Dig holes deep enough to just cover the roots and wide enough you can spread roots horizontally. Leave at least 5 meters between plants.
3. Mix about 120 ml of bone meal or superphosphate into the soil in which the plant is going to be planted. In heavy clay soils or in very sand soils, add equal parts of compost to backfill soil to improve growing conditions.
4. At least once a week for the first month, water the new transplants until the soil is soaked.

5. Apply either a dry fertilizer such as 10-10-10 or a liquid soluble one during the first growing season according to label directions.
6. Place a wooden or metal stake beside each plant to indicate its location and prevent accidental damage.
7. Mark each shrub with flagging tape or some other durable identification. Label the flagging tape with the name of the plant variety for each shrub.

2. Annual Care

Materials

- ❑ 5-10-10 fertilizer or its equivalent
- ❑ Mulch: peat moss, bark, well-rotted sawdust or similar organic matter

1. Spread 50 g of 5-10-10 fertilizer or its equivalent evenly around each plant. Shrub fertilizer stakes may be used instead.
2. Keep the soil within 30 cm of the base of each plant free of grass and weeds with a mulch of peat moss, bark, well-rotted sawdust, wood chips, or similar organic material.
3. During a long dry period, you may have to water the plants.
4. During the first and second years, the plants may need extra care to make sure that they are strong. After that, fertilizers may not be needed. Check periodically to make sure that they are in good health.

3. Pruning

Plants should be pruned every 5-10 years to maintain good shape. Prune lilacs immediately after bloom in spring because the following year flower buds are formed on new wood that grows after bloom. Avoid fall pruning because it will destroy the buds for the next year. Old, dried-up flowers may be cut off if desired so that the shrubs do not look unsightly.

One or more of the older main stems at the base of the plant may be removed and some, or all, of the remaining stems trimmed back to maintain the size and shape desired. Never remove more than 1/3 of the plant at any one time.

4. Protection Against Disease, Pests, and Severe Weather

These plants are relatively resistant to insects and diseases. Occasionally they may be affected by powdery mildew, leaf spot, scale, or aphids. Control measures rarely are needed except for scales. Should these diseases or insects become serious, regular applications of a pesticide may be necessary. Contact the Agricultural Extension Service in your state, province or county for the latest control recommendations.

In some locations animals, such as rabbits and mice, may severely damage the plants. Wire-mesh guards around the base of the plants help to control such damage.

For winter protection in areas of little snowfall, 5-10 cm of mulch around the base of each plant will protect its roots from frost damage. To prevent breakage from ice, wrap stems together loosely with twine or place burlap (such as from a feed bag) on a frame over the plant. Do not use plastic.

Frequently Asked Questions

1. Are these plants invasive?
No. Lilacs are not invasive. The clonal lilacs are also sterile hybrids that produce no seeds.

2. Can we plant both clonal and common lilacs?
Yes. Comparison data between the clonal and common lilacs are highly desirable.

3. What do I do if a lilac shrub dies?
On the Lilac Site Definition page, record when the plant died. You can plant another lilac shrub and enter the new planting information.

4. What if all our lilacs die?
Plant new lilacs and define a new site.

Common and Clonal Lilac
Site Definition Field Guide

Task
To take photographs and locate the latitude, longitude, and elevation of your lilac site

What You Need
- ❑ *Common and Clonal Lilac Site Definition Sheet*
- ❑ *Basic GPS Field Guide*
- ❑ *GPS Data Sheet*
- ❑ GPS receiver
- ❑ Pencil or pen
- ❑ Compass
- ❑ Camera
- ❑ Flagging tape or some other durable identification
- ❑ Tape measure

In the Field
1. Fill out the top portion of the *Common and Clonal Lilac Site Definition Sheet.*
2. Identify the latitude, longitude, and elevation following the *Basic GPS Measurement Protocol.*
3. If known, record the distance and direction to, and elevation difference with, your Atmosphere Site.
4. Label each shrub with flagging tape or some other durable identification.
5. Measure the height of each lilac plant.
6. Take photos in the North, East, South, West directions. Use the compass to determine the directions.
7. Submit photos to GLOBE by mailing them to the address given in the *Implementation Guide* in the GLOBE *Teacher's Guide.*

Clonal and Common Lilac Protocol
Field Guide

Task
Observe when the five phenophases of common or clonal lilacs occur

What You Need
- ❑ *Common and Clonal Lilac Data Sheet*
- ❑ Pencil or pen

In the Field
1. Examine each lilac plant.
2. For each lilac plant, record dates of the five phenophases on the *Common and Clonal Lilac Data Sheet.* The five phenophases in order are:

   First leaf: when the widest part of the first new leaf has grown beyond the end of its bud.

   Fully leafed: when nearly all (greater than 95%) of the actively growing leaf buds have leafed

   First bloom: when at least 50% of the flower clusters have at least one open flower .

   Full bloom: when greater than 95% of the flower clusters no longer have any unopened flowers but before many of the flowers have withered.

   End of bloom: when greater than 95% of the flowers have withered or dried.

3. In the autumn, measure the height of each lilac plant. This is done once a year only. Record if the lilac plant appears to be in poor health.

Arctic Bird Migration Monitoring Protocol

Purpose

To observe when selected bird species first arrive at your study site, and to count the numbers until few or none of these birds are seen

Overview

Students select a common and easily identifiable bird species in their region and observe when the bird species first arrives. Students use binoculars or telescopes to scan a study site and count how many they see. They continue to observe every other day until few or none of the selected species can be seen.

Student Outcomes

Students will learn to identify different species of birds, their migratory patterns and behavior, as well as using standardized methods to gather scientific data.

Science Concepts

Life Science

- Organisms have basic needs.
- Organisms can only survive in environments where their needs are met.
- Earth has many different environments that support different combinations of organisms.
- All organisms must be able to obtain and use resources while living in a constantly changing environment.
- Energy for life derives mainly from the sun.
- Living systems require a continuous input of energy to maintain the chemical and physical organizations.
- The interaction of organisms in an ecosystem have evolved together over time.

Geography

- The characteristics and spatial distribution of ecosystems on Earth's surface

Scientific Inquiry Abilities

- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures, descriptions, and predictions.

Time

Field time 15 – 20 minutes (excluding travel time).

Level

All

Frequency

Every other day from about 2 weeks prior to expected arrival time until few or none of the selected bird species are seen

Materials

- *Arctic Bird Migration Monitoring Field Guide*
- *Arctic Bird Migration Monitoring Data Sheet*
- *Arctic Bird Migration Site Definition Field Guide*
- *Arctic Bird Migration Site Definition Data Sheet*
- *GPS Protocol Field Guide*
- *GPS Protocol Data Sheet*
- Compass
- Binoculars and/or telescopes
- Notebook (preferably a waterproof field-book)
- Pencils
- Bird identification book

Preparation

Decide upon study locations and the species to be monitored.

Practice using binoculars.

Use of a Bird Identification book

Prerequisites

None

Arctic Bird Migration Monitoring Protocol – Introduction

Both scientists and amateur naturalists have been recording the life cycles of plants and animals for many centuries. Since about 1850, records of climatic fluctuation and changes in distribution of plants and animals have become more reliable. These data sets are now being used to study the timing of biological events and to explore changes in bird migratory patterns (Whitfield, 2001). The data are of great importance and allow scientists to make better predictions about future impacts of climate change.

Ornithologists believe climate to be a primary factor influencing bird distribution. Many bird species that breed in the Arctic and near Arctic zones migrate in autumn to wintering areas. The general direction of migration is from pole to equator, but birds may go in other directions such as east or west (Harrison, 1982).

Data show an increase in temperature in northern Europe in the early 20th century (Icelandic Ministry of Environment, 2000). A gradual response by birds became apparent, and in the early 1950s, James Fisher listed 42 species that were spreading into Scandinavia from the south or east (Burton, 1995). Finnur Gudmundsson listed seven southern species that established themselves as breeding birds in Iceland between 1890 and 1950. Partially migratory species (species that have a portion of the population stay in the same place all year round), winter visitors and occasional visitors increased in Iceland. Increased temperature also caused northern species to retreat farther north (Gudmundsson, 1951). Since the 1950s, there has been a decrease in temperature in northern Europe and Iceland and some birds have responded by shifting southwards to breed. Other regions in the world have shown an increase in temperature during the same time period (Burton, 1995). It is important to realize that climate change can differ between areas and scientists would like a better understanding of how birds respond in different places.

Many factors affect bird migratory behavior. Temperature is often thought of as the obvious explanation for distributional limits of birds and other animals, but it also has secondary effects. For example, temperature affects vegetation growth and seed and insect availability for birds to eat. Precipitation also affects food availability and the types of land cover in an area. In addition to climatic changes, human activity has had an impact on bird distribution and abundance by changing land cover (Harrison, 1982).

Data from the GLOBE *Arctic Bird Migration Monitoring Protocol* will be important to scientists now and in the future. Gathering data in many different locations will increase knowledge, not only about bird migration patterns and its connection to climate changes, but also on changes in abundance and species distribution. Furthermore, the data collected can be compared with other phenological data gathered by your school or in cooperation with other schools and other institutions to get a more complete picture of the Earth system.

Teacher Support

Selecting a Bird Species

- First, students need to gather information about birds in your area. What are common birds in your area? Which species breed in your area? Which species stay the whole year? Which species are migratory and only stay for part of the year? Information on the bird species and their spring arrival time should be easy to locate. Most communities have a network of bird watchers who can help you. As well, you can contact experts at universities or government agencies.
- The species you choose needs to be common and easily identified. We suggest that you do not select hidden or secretive species or species that rest and/or feed in trees or on land where they cannot be easily seen as this makes it difficult to estimate how many are present at your site.
- What is the migratory pattern of the species you select? What time of the year do the birds migrate to your area? You may want to select a bird species that arrives in the early spring so that student observations can fit into the school calendar.
- You need to find information on where the birds can be found in your area.
- It would be helpful to learn about your selected species. Where does it come from? What does it eat? Does it gather in flocks at certain times, e.g. to feed on estuaries or on lakes? Does it come to your area to breed, or is it on a stopover and will be migrating farther to breed?

Following are some examples of bird species you can observe that can be easily identified and seen.

Arctic tern *(Sterna paradisaea)*

Eurasian Golden Plover (*Pluvialis apricaria*)

Oystercatcher *(Haematopus ostralegus)*

Site Selection

Depending on where you live, select a site in an estuary, a field, a shoreline, lake or pond, or ocean. A woodland or forest is more difficult since it can be difficult to see birds in the trees.

Select a site based on the known distribution of your selected species in your area. Students will make frequent visits, so the site needs to be fairly close to your school or to homes of students.

The location must be accessible to students so birds can be counted accurately. Observers need to be far enough away from the birds not to disturb them, but close enough to count them. You can use binoculars or telescopes to see the birds better at a distance.

The size of the site needs to be manageable for students to observe the birds. A very large area can be difficult for students to accurately count the birds. However, a large area can be divided into segments and the students can be divided into groups. Each group would count birds from one segment. Later the numbers from the groups can be pooled together to get the total number of birds on your entire study site.

Do not choose an area where the birds are fed, as feeding may affect the bird numbers and would not show the natural number of birds frequenting a place with a natural food source.

Avoid areas used for hunting if you are observing birds during hunting seasons.

Bird Monitoring

As the arrival time of birds can vary between years, start monitoring your site one or two weeks before the expected arrival.

Choose a convenient time of day to observe. You need enough light to see the birds. Go at about the same time each day. If you are studying a shorebird along an ocean, make your observations within two hours of low tide. Look at tide tables for your area to know when to go.

If you observe anything unusual during your observations, such as a bird of prey or high winds, record on the comment section on the *Arctic Bird Migration Monitoring Data Sheet*. Additional information can often help explain discrepancies or unusual values in the data.

Each year students can select which bird species they would like to monitor. However, scientists would like to have at least one species that is consistently monitored each year.

Continue observing until all or most of the selected bird species have left your area.

Student Preparation

Familiarize the students with the study site and methods before students start to observe and count birds.

Have the students visit the site together and practice using binoculars or telescopes to count birds while scanning the area. Since you will be practicing before your chosen bird species arrives, decide beforehand what you will count. It could be all birds on the site or one species familiar to all students. It takes practice to use binoculars for counting birds. Have the students adjust the focus as necessary so that the data collected are reliable.

Have the students compare notes on how they did, how many birds did they see and what problems they had or can foresee.

Ideas and Variations

- It is suggested that students work in groups of at least two so that one student can record the count as the other student observes the birds.
- If there are many students in your class you could choose more than one species of bird. Divide the students into groups and each group could be responsible for one species.
- Separate the students into different groups and observe the same species at different locations. Students could compare arrival times and numbers of birds among the sites and explore reasons why there may be differences.
- Choosing two different locations with different species would also be interesting, as the students could also study why different species choose different locations.
- Have students determine the difference in elevation between the *Arctic Bird Migration Study Site* and the nearest Atmosphere Study Site. They should do this using the corrected elevation values supplied by GLOBE. This may indicate that temperature and other variables are different at the two sites.
- Students could share what they learn about their chosen species by making posters, giving oral presentations, or writing essays.

Questions for Further Research

Does temperature affect the arrival time of selected bird species?

Do other weather or ocean conditions affect the arrival and departure of selected bird species?

Is there a difference in arrival time between bird species? If so, why?

How does the land cover in your area affect the types of birds you see?

Do different bird species react differently to changes in temperature?

Would an unusually wet spring affect the migratory patterns of birds?

References

Burton, John F. 1995. *Birds & Climate Change*. Biddles Limited. Surrey. Great Britain.

Guomundsson, Finnur. 1951. *The effects of the resent climatic changes on the bird life of Iceland.*

Harrison, Colin. 1982. *An Atlas of The Birds of the Western Palearctic.* William Collins Sons & Co Ltd. Glasgow. Great Britain.

Veourfarsbreytingar og afleioingar peirra. Sk´yrsla vísindanefndar um loftslagsbreytingar (Meteorological changes and consequences. Scientific Committee Report). October 2000. Umhverfisráuneytio, Reykjavík (Icelandic Ministry of Environment, Reykjavík).

Whitfield, John. 2001. *The budding amateurs.* Nature 414: 578-579.

Arctic Bird Migration Monitoring

Site Definition Field Guide

Task

Measure the latitude, longitude and elevation, take photos and describe your Arctic Bird Migration Monitoring Study Site.

What You Need

- ❑ GPS receiver
- ❑ *Basic GPS Field Guide and Data Sheet*
- ❑ *Arctic Bird Migration Monitoring Site Definition Data Sheet*
- ❑ Camera
- ❑ Compass
- ❑ Pencil

In the Field

1. Fill out the top portion of the *Arctic Bird Migration Monitoring Site Definition Data Sheet*.
2. Determine the latitude, longitude, and elevation following the *GPS Protocol Field Guide*. Record these values on your *Arctic Bird Migration Monitoring Site Definition Data Sheet*.
3. Take photographs in the North, East, South, and West directions. Use the compass to determine the directions. Remember that you want true north and not magnetic north.
4. Describe the type of site: field, estuary, lake or pond, ocean, woodland/forest, or other.

Arctic Bird Migration Monitoring Protocol

Field Guide

Task

To observe the number of birds of your selected species at your Study Site

What You Need

- ❑ Binoculars or telescope
- ❑ Bird Identification book
- ❑ Pencil
- ❑ *Arctic Bird Migration Monitoring Data Sheet*

In the Field

1. Fill out the top part of the *Arctic Bird Migration Monitoring Data Sheet*.
2. Record date and starting time.
3. Using the binoculars or telescope, start scanning the study site from one side to the other side. Count the number of birds of the selected species. Record the number of birds you see as you scan the site.
4. Record the end time of monitoring.
5. If your site is located by the ocean, record the approximate time of low tide.

Arctic Bird Migration Monitoring Protocol – Looking at the Data

An Example of a Student Project

Oystercatchers (Haematopus ostralegus) Observed on Akureyri Estuary

Here is an example of a possible student research project using Oystercatchers data collected between 1994-1999. It is based on data collected by adult volunteers in Akureyri, Iceland. Bird enthusiasts in Akureyri have been recording birds at the estuary since 1993. They visit the estuary approximately once a week and record all the different species.

Figures EA-BI-1 through EA-BI-6 show the number of Oystercatchers observed at the estuary. Each figure shows the data for a single year from 1994 to 1999. The y-axis represents the number of birds observed and the x-axis represents the day in the year starting from January 1. May 1, for example represents day number 121 in a normal year and day number 122 in a leap year. It should be noted that the data set is not consistent between years. The number of days visited to take observations differs, and for some years, observations were not started before birds started to arrive in the spring.

Figure EA-BI-1: Oystercatcher arrival to the Akureyri estuary in 1994

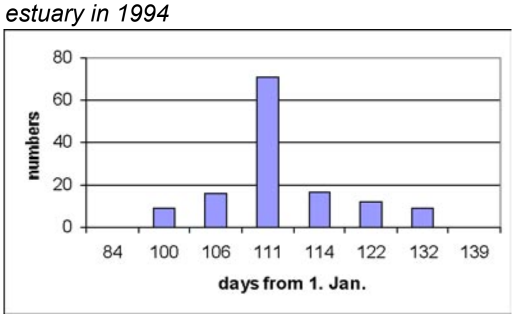


Figure EA-BI-2: Oystercatcher arrival to the Akureyri estuary in 1995

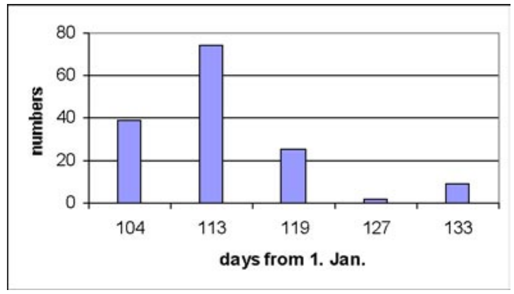


Figure EA-BI-3: Oystercatcher arrival to the Akureyri estuary in 1996

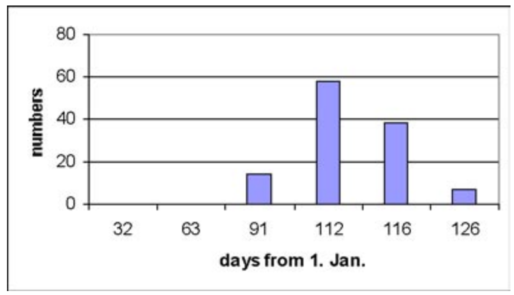


Figure EA-BI-4: Oystercatcher arrival to the Akureyri estuary in 1997

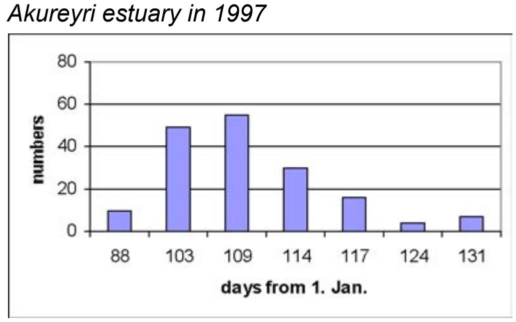


Figure EA-BI-5: Oystercatcher arrival to the Akureyri estuary in 1998

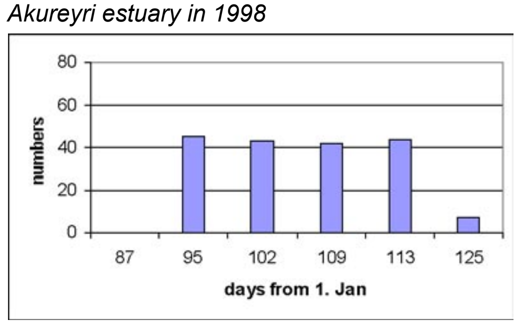
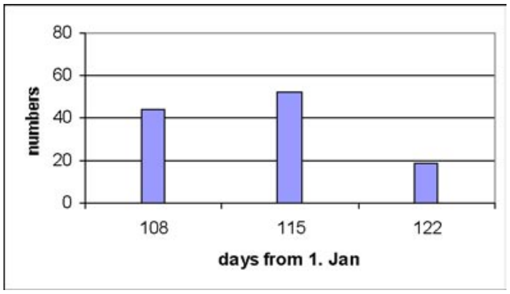


Figure EA-BI-6: Oystercatcher arrival to the Akureyri estuary in 1999



After examining Figures EA-BI-1 through EA-BI-6, one can see that in 1994 and 1995, the maximum numbers of Oystercatchers in the estuary are higher than in the following years. This can be shown better in Figure EA-BI-7 comparing the maximum number of Oystercatchers observed each year.

The year 1998 shows a slightly different pattern than the other years. The maximum number of birds observed in 1998 was observed earlier in the spring (day 95 compared to day 111, 113, 112, 109, and 115). Figure EA-BI-8 compares the days when the maximum number of Oystercatchers was observed each year. In 1998, the birds arrived more or less all at once, stayed for about one month and then left together. There was no gradual increase or decrease in numbers as shown for the other years.

Figure EA-BI-7: Maximum number of Oystercatchers observed on the Akureyri estuary 1994 – 1999

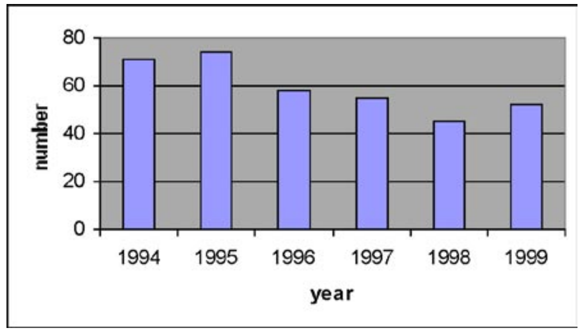
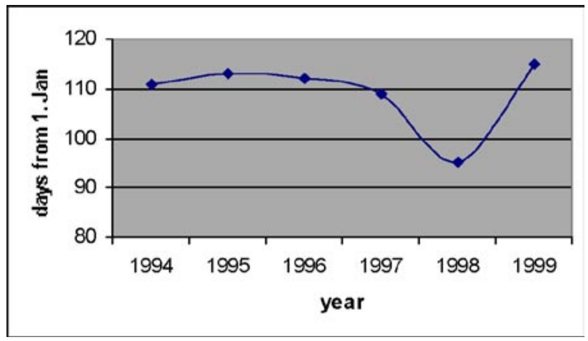


Figure EA-BI-8: Day of maximum number of Oystercatchers on the Akureyri estuary 1994 – 1999.



Now that some patterns and possible deviations from a general trend have been seen, let's explore possible connections with atmospheric measurements such as temperature. Table EA-BI-1 shows the average air temperature for the month of April for each year. The days when the maximum number of Oystercatchers were observed are in April each year.

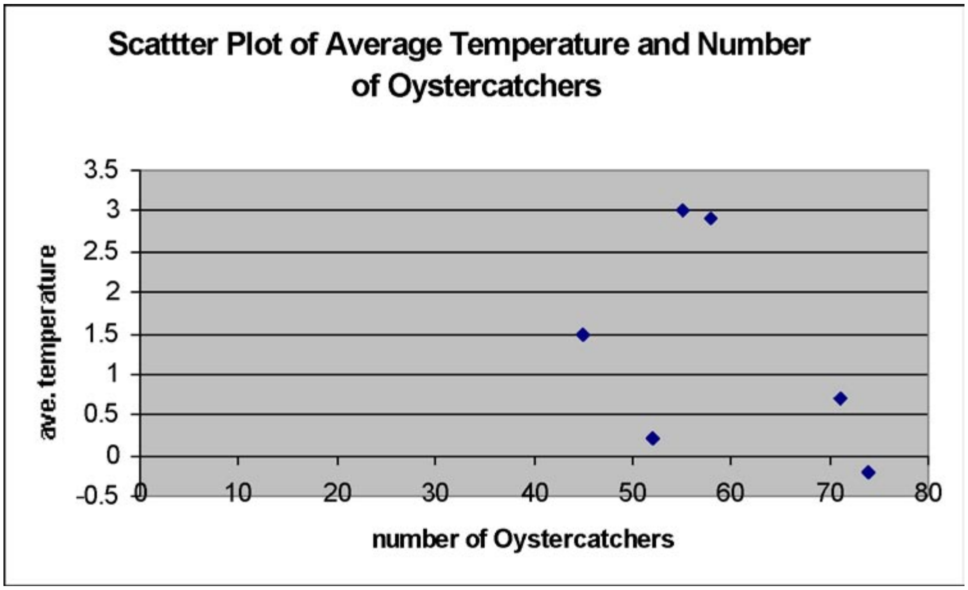
Table EA-BI-1: Maximum number of birds seen on Akureyri estuary each year, day maximum number of birds was observed, and average temperature (°C).

Year	Day number	Max number	°C April
1994	111	71	0,7
1995	113	74	-0,2
1996	112	58	2,9
1997	109	55	3
1998	95	45	1,5
1999	115	52	0,2

Note: some countries use a decimal point instead of a comma.

A scatterplot (Figure EA-BI-9) of the average temperature in April and the maximum number of Oystercatchers observed shows no correlation.

Figure EA-BI-9



According to this analysis, there is a poor correlation between monthly average temperature and the date when the maximum number of birds was observed. It might be more advisable to use the temperature from where the birds winter and not their destination at Akreyri. Perhaps there would be a better correlation with those temperature values. It is also possible that the data set is not yet sufficient and needs more years to demonstrate a pattern that correlates with monthly average temperature.

Seaweed Reproductive Phenology Protocol

Purpose

To classify and count the reproductive phenological phases of receptacles on selected seaweed species

Overview

Students will classify and count the reproductive phases of seaweed plants within a 1-meter x 1-meter plot in the inter-tidal zone.

Student Outcomes

Students will be able to,

- identify reproductive stages of seaweed plants;
- graph the relative abundance of the reproductive stages;
- compare when reproductive stages occur in different places; and
- explore relationships between reproductive stages and climate factors.

Science Concepts

Life Sciences

Organisms have basic needs.

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Plants and animals have life cycles.

Energy for life derives mainly from the Sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Students will learn how to identify the different reproductive stages during plant growth.

Students will make connections between climate and seaweed reproductive cycle.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

30 –45 minutes

Level

Middle and Secondary

Frequency

Once a month for four months in a row during low tides

Materials and Tools

GPS receiver

GPS Field Guide

GPS Data Sheet

Seaweed Reproductive Phenology Site Definition Field Guide

Seaweed Reproductive Phenology Site Definition Data Sheet

Seaweed Reproductive Phenology Protocol Field Guide

Seaweed Reproductive Phenology Protocol Data Sheet

Documenting Your Hydrology Study Site Field Guide (Hydrology Investigation)

Ruler in millimeters

Clinometer

Compass

Tide tables for locality

Pencil or pen

Camera

2-4 meter sticks or quadrat (see *Freshwater Macroinvertebrate Protocol* in *Hydrology Investigation*)

Preparation

Learn how to use tide tables

Practice identifying the seaweed reproductive stages using the photos

Learn how to identify seaweed species

Prerequisites

None

Introduction

As with budburst and blooming of plants on land, plants in the oceans go through growing and reproductive cycles. Seaweed reproductive phases are an example of plant phenology. The study of when these phases occur can help scientists better understand how these plants respond to climatic factors. With time, seaweed reproductive phenology can be used to study the effects of climate change.

Teacher Support

Who can do this protocol?

To do this protocol you must live by the ocean in an area where at least one of the selected seaweed species is found. The seaweed species used in this study are: *Ascophyllum nodosum, Fucus distichus, Fucus spiralis, Fucus vesiculosus, Pelvetia canaliculata,* and *Fucus serratus.*

Distribution of Selected Seaweed Species

Ascophyllum nodosum is distributed in the North Atlantic (South & Tittley 1986). On the European coast it is found from Portugal in the south and northwards to northern Norway. It grows around the UK and Ireland, Faeroe Islands, Iceland, Jan Mayen, and southern Greenland. On the North American side it is found from Delaware in the south to Baffin Island and Hudson Bay in the north.

Fucus distichus is found in the North Atlantic and the North Pacific. It grows along the coast of Norway north to Spitzbergen. It grows on the west coast of UK and Ireland, Faeroe Islands, Iceland, Jan Mayen, and West Greenland. In North America it grows from Virginia in the south to Baffin Island in the north (South & Tittley 1986). *Fucus distichus* grows on the Pacific coast of North America from Oregon to Alaska (Lüning 1990).

Fucus spiralis has its distribution range in the North Atlantic and the North Pacific. It is found in the Azores and Portugal and from there its distribution extends northwards to northern Norway and Bear Island. *F. spiralis* is found around UK and Ireland, Faeroe Islands, and Iceland. On the Atlantic coast of North America it has been found in the range from Delaware north to Baffin Island in Canada (South & Tittley 19869. On the Pacific coast of North America the species is found from Oregon northwards to Alaska (Lüning 1990).

Fucus vesiculosus is found in the Azores and along the Atlantic coast of Europe from Portugal to northern Norway and Spitzbergen. It is found around the coast of UK and Ireland, Faeroe Islands, Iceland, and Greenland. On the Atlantic coast of North America it is found from Virginia in the south, north to Baffin Island and Hudson Bay in the north (South & Tittley 1986).

Pelvetia canaliculata is found along the coast of Europe from Portugal in the south to northern Norway. It is found around the coast of UK and Ireland, Faeroe Islands and southwestern Iceland (South & Tittley 1986). *P. canaliculata* is not found in North America.

Site Selection

The site needs to be an easily accessible rocky shore. It is preferable to have the site away from areas with industrial or residential activities for pollution and human activities may affect when seaweed reproduces so that the seaweed reproduction does not reflect regional climatic influences. The object of the study is to learn connections between the seaweed phenology and climate factors.

Your students will be visiting the site four times (once each month). The students need to visit the same plot each time. To do this, you need to establish a permanent marker. If there is a distinctive feature on the beach (such as an unusually large boulder), use the feature to identify your location. Or, you could pound a reinforcing bar into the beach.

Frequency of Sampling

Sampling should be done once a month for four consecutive months. *Pelvetia canaliculata*, *Fucus vesiculosus*, and *Fucus spiralis* are better sampled in the fall. Choose *Ascophyllum nodosum* or *Fucus disticus* if you would like to sample in the spring. If you have any questions about which species to choose and when to sample, please contact GLOBE.

It is not necessary to sample precisely at the same time each month. Instead, look at tide-tables for your area and select a day when the tide is at its lowest during the month. The time between two hours before and after the low tide is the recommended time to sample.

Advance Preparation

You may want to visit the site before the students to determine how safe the shore is for the students and to see what types of seaweed are present.

Find out what species of seaweed are in your area.

Find out what the tidal range is for your area.

Make color photocopies of the reproductive stages of the seaweed species your students will be observing. Depending on your site and your educational objectives, your students could be studying one or more species.

Student Preparation

Familiarize students with the parts of seaweed plants

Practice identifying the different reproductive phases using the photos provided for the species in your area before going to the site to collect data.

Practice using tide tables to determine when you should sample.

Measurement Procedures

It is requested that all the receptacles on the plants are counted. If there is one species in the plot, then count the receptacles on all the plants of that species. If there are multiple seaweed species, then you can either count only one species or all species. It is preferable to count the receptacles of each species. It is important to keep track of which receptacles go with which species.

Start counting the receptacles at one corner and keep track of the plants whose receptacles have already been counted. Have students work in teams with two or more students classifying the reproductive stages. You can rotate students so that a large group gets an opportunity to classify the stages. These plants are very strong and durable; however, students should handle the plants with care so that they are not harmed.

You can set up multiple plots. If there are two or more seaweed species on the beach, a group of students at one plot can count the receptacles of one species while another group of students at a second plot can count the receptacles on a second seaweed species.

Reproductive phases

The descriptions in the tables below along with the photos of the reproductive stages will help with classification of the stage at your site.

Table EA-SW-1: Receptacle developmental stages for Ascophyllum nodosum.

Stages	Description
1	Receptacles distinguishable as small, green, flat and circular outgrowth from the main branches.
2	Receptacles inflated, green or even yellowish, same color as on the stipe (stems).
3	Receptacles inflated, with nipples, yellow or orange in color as on the stipes (stems). Plants without receptacles are green.
4	Receptacles ruptured and torn, orange in color (release of gametes).
5	New side branches starting to develop. No receptacles distinguishable.

Table EA-SW-2. Receptacle developmental stages for Fucus distichus.

Stages	Description
1	Receptacles small elongated, with a rough surface, greenish as the plant.
2	Receptacles greenish, elongate with nipples, sometimes become 1/4 inflated at the apex.
3	Receptacles brownish, elongate with nipples, about 1/3 inflated.
4	Receptacles ruptured, starting from the apex proceeding inwards (gamete release).
5	No receptacles.

Table EA-SW-3. Receptacle developmental stages of Fucus spiralis.

Stages	Description
1	Receptacles small, light brown, spherical, at the tips of dark branches.
2	Receptacles large, green spheres with nipples at the tips of reddish branches.
3	Receptacles large, red/yellow spheres with nipples on red, often worn branches.
4	Receptacles red or yellow spheres, ruptured (gamete release).
5	No receptacles.

Table EA-SW-4: Receptacle developmental stages for Fucus vesiculosus.

Stages	Description
1	Receptacles small elongated spheres at the tips of the branches, green in color as the branches.
2	Receptacles inflated with nipples, green in color as the branches.
3	Receptacles reddish or orange in color, inflated, with nipples.
4	Receptacles ruptured, reddish or orange in color (gamete release).
5	No receptacles

Table EA-SW-5: Receptacle developmental stages of Pelvetia canaliculata.

Stages	Description
1	Receptacles distinctively thicker than the blades but with the same color.
2	Receptacles inflated, green or even yellow, same color as the blade bearing the receptacle.
3	Receptacles inflated with nipples, yellow or orange in color, same color as the blade bearing the receptacle. Plants without receptacles green.
4	Receptacles ruptured (gamete release), often only orange blades are found colored as the blade bearing the receptacle.
5	No receptacles

Table EA-SW-6: Receptacle developmental stages of Fuccus seratus.

Stages	Description
1	Receptacles flat. Nipples are green and distinctive as flat receptacles on top of the branch.
2	Receptacles are not inflated but the nipples are light brown or red.
3	The whole receptacle is colored like the nipples in stage 2. Red spots are very prominent and the receptacles are often ruptured.
4	No receptacles

Ascophyllum nodosum

Stage 1:

Receptacles distinguishable as small, green, flat and circular outgrowth from the main branches

Stage 2:

Receptacles inflated, green or even yellowish, same color as on the stripe (stems).

Stage 3:

Receptacles inflated, with nipples, yellow or orange in color as the stipes. Plants without receptacles are green.

Stage 4:

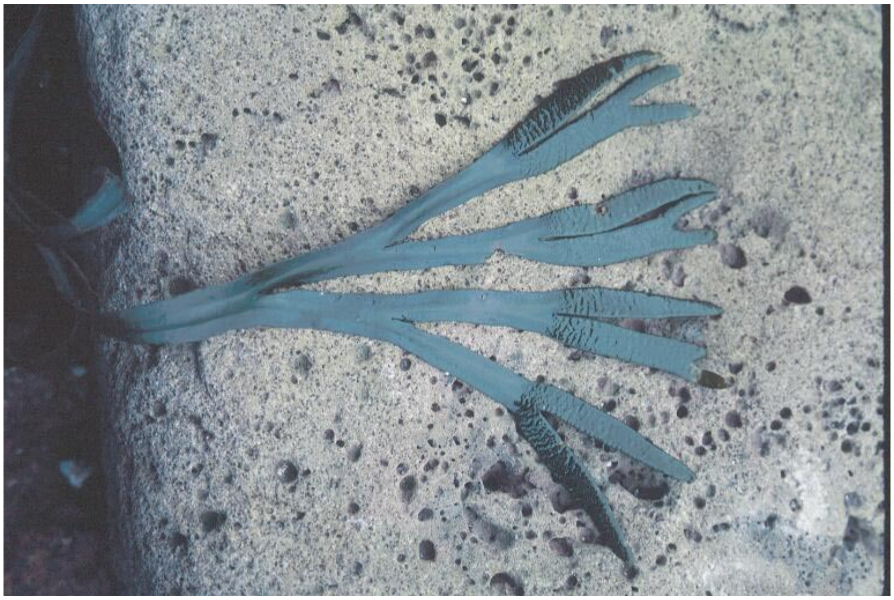
Receptacles ruptured and torn, orange in color (release of gametes).

Stage 5:

New side branches starting to develop.

No receptacles distinguishable.

Fucus distichus



Stage 1:

Receptacles small elongated, with a rough surface; greenish as the plant

Stage 2:

Receptacles greenish, elongate with nipples, sometimes inflated at the apex (up to 1/4).

Stage 3:

Receptacles brownish, elongate with nipples, about 1/3 inflated.

Stage 4:

Receptacles ruptured, starting from the apex proceeding inwards (gamete release).

Stage 5:

No receptacles.

Fucus spiralis

Stage 1:

Receptacles small, light brown, spherical, at the tip of dark branches.

Stage 2:

Receptacles large, green spheres with nipples at the tip of reddish branches

Stage 3:

Receptacles large, red/yellow spheres with nipples on red often worn branches

Stage 4:

Receptacles red or yellow spheres, ruptures (gamete release)

Stage 5:

No receptacles.

Fucus serratus

Stage 1

Receptacles flat. Nipples are green and distinctive as flat receptacles on top of the branch.

Stage 2

Receptacles are not inflated but the nipples are light brown or red.

Stage 3

The whole receptacle is colored like the nipples in stage 2. Red spots are very prominent and the receptacles are often ruptured.

Stage 4

No receptacles

Fucus vesiculosus

Stage 1:

Receptacles small, elongated spheres at the tips of branches, green in color as the branches

Stage 2:

Receptacles inflated with nipples, green in color as the branches

Stage 3:

Receptacles reddish or orange in color, inflated with nipples

Stage 4:

Receptacles ruptured, reddish or orange in color (gamete release)

Stage 5:

No receptacles.

Pelvetia canaliculata

Stage 1:

Receptacles distinctively thicker than the blades but with the same color

Stage 2:

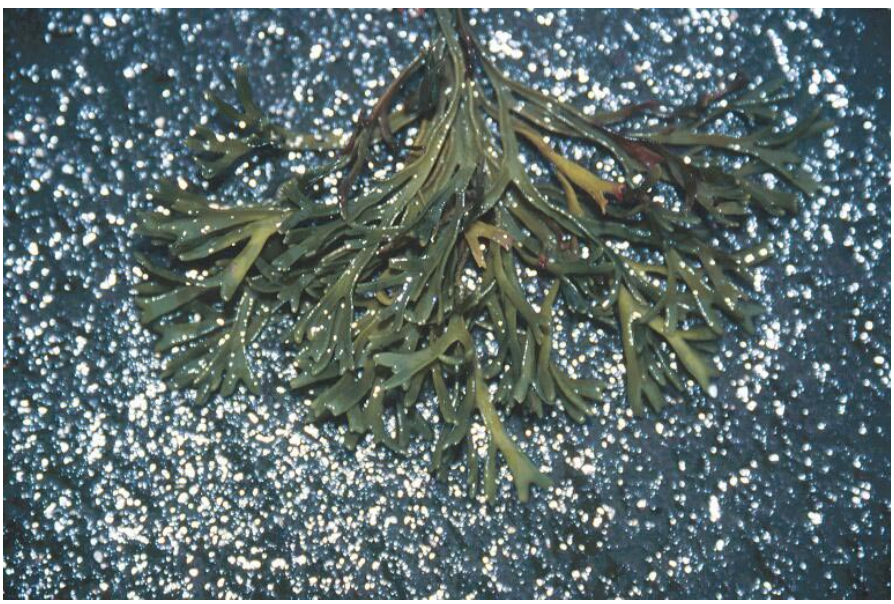
Receptacles inflated, green or even yellow, same color as the blade bearing the receptacle.

Stage 3:

Receptacles inflated with yellow nipples, yellow or orange in color, same color as the blade bearing the receptacles. Plants without receptacles are green.

Stage 4:

Receptacles ruptured (gamete release), often only orange blades were found. Colored as the blade bearing the receptacle.



Stage 5:

No receptacles.

Measuring Rocks

To define the site, students are asked to report the most common rock size on the beach. Rocks are classified according to their size. The size category is defined by the length of the longest axis. The size categories are shown in Table EA-SW-1.

Table EA-SE-1 Size Categories for Rocks

Category		Length of longest axis
Boulders	large	>1000 mm
	medium	500-1000 mm
	small	256-500 mm
Cobbles		64-256 mm
Pebbles		16-64 mm
Gravel		4-16 mm

Connections to Other Protocols

It is not required, but would be very helpful to the scientists to have hydrology measurements taken, in particular water temperature, transparency, and salinity.

Reading a Tide Table

Tides are caused by the gravitational pull of the moon and the sun on Earth. Because the moon is so much closer to Earth than the sun, the moon exerts the greater pull. The most extreme tides, called spring tides occur during full and new moons when Earth, moon, and sun are in a line. During quarter and three quarter moons, the moon, Earth and sun form a right triangle and the tidal range (the difference between high and low tides) is the smallest. These tides are called neap tides.

You need a tide table calculated for the local area to determine the tides in your area. The tide table will give you the dates, times and water levels for high and low water. These are available from government agencies, private fisheries and tourist agencies. They can also be found on the web, in newspapers, or published as booklets. Because tides vary each year with the lunar cycle, it is necessary to use a tide table calculated for the current year. Tides also vary with each locality, so try to get a tide table for the exact area you are observing, or for the closest area for which tide tables are available. You may need to consult two tide tables - a primary tide tabled based on a tide station in the general region of your site and an auxiliary tide table with corrections for time and tidal height for your particular site.

Most areas have two low and two high waters per day with one set of high and low more extreme than the others. This is called a mixed semidiurnal tide (mixed because the two tide cycles are uneven and semidiurnal because there are two sets per day). The two high and low water levels occur over approximately 24 hours with each high and low approximately six hours apart. Tide cycles actually occur over a lunar day, which is 24 hours and 50 minutes long. The two low tides in a day occur on average every 12 hours 25 minutes. The time of the first low tide each day occurs on average approximately 50 minutes later than the day before. Local topographic features may cause these times to vary.

To determine the tidal height at a particular time and date, read on the tide table the times of high and low water for the date you sampled that bracket the time you sampled. Determine whether the tide was coming in or going out when you sampled by assuming that the tide turned (changed direction) at the times of low and high tides. For instance if you sampled at 4 PM on August 1, 2002 (Table EA-SW-2), the tide was coming in because it was low at 1:06 PM and high at a later time, 7:40 PM.

Table EA-SE-2: Tide Table for Aberdeen, Washington

Tide Predictions (High and Low Waters) August, 2002 Source: NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 Th	131am	L 0.6	730am	H 2.0	106pm	L 0.8	740pm	H 2.6
2 F	233am	L 0.5	841am	H 1.9	206pm	L 1.0	832pm	H 2.7
3 Sa	335am	L 0.3	956am	H 1.9	313pm	L 1.1	928pm	H 2.7
4 Su	432am	L 0.1	1105am	H 2.0	417pm	L 1.1	1024pm	H 2.8
5 M	526am	L -0.2	1204pm	H 2.2	516pm	L 1.0	1118pm	H 2.9
6 Tu	616am	L -0.4	1256pm	H 2.3	611pm	L 0.9		
7 W	1209am	H 3.0	703am	L -0.6	143pm	H 2.5	702pm	L 0.8
8 Th	1258am	H 3.2	747am	L -0.7	228pm	H 2.6	751pm	L 0.6
9 F	147am	H 3.2	831am	L -0.8	309pm	H 2.7	839pm	L 0.5
10 Sa	237am	H 3.2	913am	L -0.7	349pm	H 2.8	927pm	L 0.3
11 Su	327am	H 3.2	955am	L -0.6	428pm	H 2.9	1017pm	L 0.2
12 M	419am	H 3.0	1037am	L -0.4	508pm	H 3.0	1109pm	L 0.1
13 Tu	514am	H 2.8	1121am	L -0.1	549pm	H 3.0		
14 W	1206am	L 0.1	614am	H 2.5	1209pm	L 0.2	634pm	H 3.0
15 Th	108am	L 0.1	721am	H 2.3	104pm	L 0.5	725pm	H 3.0
16 F	215am	L 0.0	837am	H 2.1	206pm	L 0.8	824pm	H 2.9
17 Sa	323am	L 0.0	956am	H 2.1	313pm	L 0.9	928pm	H 2.9
18 Su	428am	L -0.1	1110am	H 2.2	419pm	L 1.0	1032pm	H 2.9
19 M	527am	L -0.2	1211pm	H 2.3	521pm	L 0.9	1130pm	H 2.9
20 Tu	618am	L -0.3	101pm	H 2.5	616pm	L 0.8		
21 W	1221am	H 2.9	703am	L -0.3	142pm	H 2.6	705pm	L 0.7
22 Th	106am	H 2.9	744am	L -0.3	220pm	H 2.7	750pm	L 0.6
23 F	148am	H 2.9	821am	L -0.3	254pm	H 2.7	831pm	L 0.5
24 Sa	228am	H 2.8	856am	L -0.2	326pm	H 2.7	910pm	L 0.5
25 Su	307am	H 2.8	928am	L 0.0	355pm	H 2.7	949pm	L 0.4
26 M	346am	H 2.7	1000am	L 0.2	423pm	H 2.7	1027pm	L 0.4
27 Tu	426am	H 2.5	1029am	L 0.3	450pm	H 2.7	1107pm	L 0.4
28 W	510am	H 2.3	1058am	L 0.5	519pm	H 2.7	1152pm	L 0.4
29 Th	600am	H 2.2	1129am	L 0.8	551pm	H 2.7		
30 F	1244am	L 0.4	659am	H 2.0	1208pm	L 1.0	633pm	H 2.6
31 Sa	146am	L 0.4	810am	H 2.0	113pm	L 1.2	730pm	H 2.6

Note: Heights in this table are in meters. Many tide tables in the United Sates and in Canada are in feet. To convert feet to meters, divide the data by 3.28 ft/m.

All tide tables (including this one) are in local time. You will need to convert to UT.

To determine the time and date of the lowest tide for a particular month, use your tide table to find the heights of the tides over the entire month. Which number is lowest (including negative numbers)? This is the lowest tide of the month when the water recedes the farthest from the shore. Which number is the highest? This number is likely to fall just after the lowest tide. Look at the illustration for the tide table for Aberdeen, Washington for August 2002 to determine the times and dates of highest and lowest tides for that month. The most extreme low tide of –0.8 meters occurred on Aug 9th at 08:31 local time. A high tide of 3.2 meters occurred 6 hours 44 minutes earlier at 01:47 local time.

Zero tide datum (also expressed as + 0, or "plus 0") is a measure of the average low tide level. There are two different definitions used worldwide for the zero tide datum: mean lower low water and mean low water. Mean lower low water is the *mean of the lowest tides* for that area. Mean low water is *the mean of all of the low tides* for that area. The zero tide datum will be found in the legend of the tide table. Students will need to check off on the data sheet which definition of zero tide datum is used on their tide table.

In interpreting your data, it is important to know which zero tide datum is used on your tide table. The negative numbers refer to water levels below the zero tide datum for your area. For example, a tide level of –0.5 is read as "minus one half meter below the zero tide level".

Helpful Hints

- A quadrat is not necessary, but may make defining the 1-meter x 1-meter plot easier in the field. The *Instrument Construction* section in the *Hydrology Investigation* shows how a quadrat can be made.
- Put the color photos of the reproductive stages in clear plastic covers so that the photos do not get wet or damaged.

Questions for Further Investigation

How does water temperature affect when the reproductive phases occur?

Do you expect much difference in when the reproductive phases occur from one year to the next?

Do storms affect when the reproductive phases occur?

Does the transparency of water affect seaweed reproduction?

References

Lüning K. 1990. *Seaweeds; Their environment, Biogeography, and Ecophysiology*. A Wiley-interscience publication. 250 p.

South G.R. & Tittley I. 1986. *A check list and distributional index of the benthic marine algae of the North Atlantic ocean.* Huntsman Marine Laboratory and British Museum (Natural History). St Andrews and London, 76 p.

Seaweed Reproduction Phenology Site Definition

Field Guide

Task

To measure the beach aspect, beach slope, locate the longitude and latitude of your site, describe the dominant size of the beach substrate (rocks) and take photos.

What You Need

- ❑ GPS receiver
- ❑ *GPS Protocol Field Guide*
- ❑ *GPS Data Sheet*
- ❑ *Seaweed Phenology Site Definition Sheet*
- ❑ *Documenting Your Hydrology Study Site Field Guide* (*Hydrology Investigation*)
- ❑ Compass
- ❑ Ruler in millimeters
- ❑ Camera
- ❑ Clinometer

In the Field

1. Fill out the top section of the *Seaweed Phenology Site Definition Sheet*.
2. Draw a map of the site following the instructions in the *Hydrology Investigatio*n, *Documenting Your Hydrology Study Site Field Guide*.
3. Locate a place on the beach where you will sample.
4. Use the GPS receiver to find the latitude, longitude and elevation following the *Basic GPS Protocol*.
5. Stand perpendicular to the slope of the beach with your eyes facing the water. Measure the direction with the compass (1-360 degrees). Be sure to enter the true and not magnetic direction (aspect). 360 degrees is used for true north.
6. Work with another student whose eyes are at approximately the same height as yours. Stand several meters apart in a line perpendicular to the water's edge. The student closer to the water should site the eyes of the other student through the straw of the clinometer. Record the angle (slope) on the *Seaweed Phenology Site Definition Sheet*.
7. Estimate the size of the rocks that are dominant at the site using this table. Use the ruler to measure the longest axis of some of the rocks.

Category		**Length of longest axis**
Boulders	large	>1000 mm
	medium	500-1000 mm
	small	256-500 mm
Cobbles		64-256 mm
Pebbles		16-64 mm
Gravel		2-16 mm

8. Take photos of the beach in the four cardinal directions: North, East, South, and West. Use the compass to determine direction. Use true North not magnetic north.
9. Submit map and photos to the address given in the *Implementation Guide*.

Seaweed Reproduction Phenology Protocol
Field Guide

Task
To identify the seaweed species at your site and to classify the reproductive stages of the receptacles on all the plants in a 1-meter x 1-meter plot.

What You Need
- ❑ 2 - 4 Meter sticks or a quadrat
- ❑ Photos of the reproductive stages
- ❑ *Seaweed Reproductive Phenology Data Sheet*
- ❑ Equipment and *Field Guides* for Hydrology Protocols (optional)
- ❑ Pencil or pen

In the Field
1. Locate your site. Use the meter sticks or quadrat to define the boundaries of the 1-meter x 1-meter area. Align the area so that it is parallel to the water line.
2. Identify the species you will be counting.
3. Start in a corner of the area and move systematically through the area. For each plant, classify the reproductive stage for each receptacle. Use the photos of the seaweed reproductive phenology stages to help you classify. Classify all the receptacles on all the plants in the plot.
4. Total the counts for each reproductive phase for each seaweed species.
5. Take water measurements following the protocols in the Hydrology Investigation (optional).

Seaweed Protocol – Looking at the Data

Are the data reasonable?

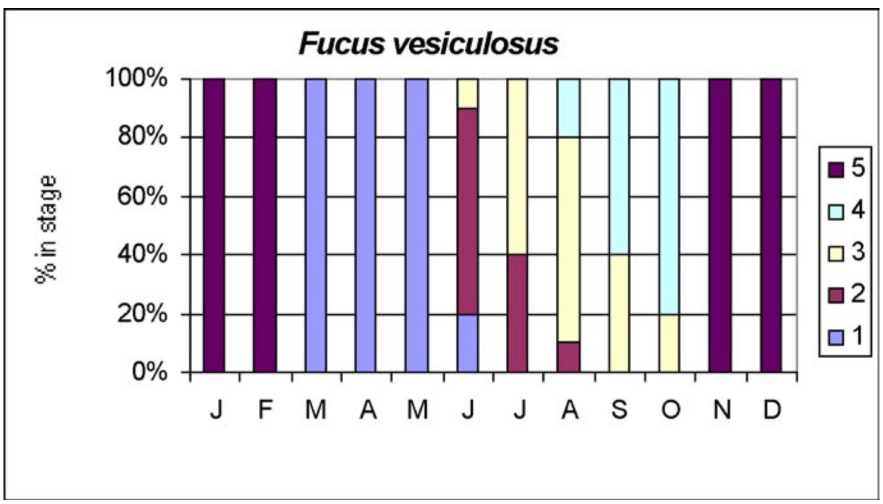
During the beginning of the reproductive cycle, the percentage of stage 1 should be large and the others smaller. As the reproductive season continues, there should be larger percentages of stages 2, 3, and 4. Eventually when the reproductive cycle is complete, stage 5 should be most common.

The following graph demonstrates this cycle. Notice in March, phase 1 is observed and then in June, stages 2 and 3 are found also. As the season progresses, only stages 3 and 4 are seen (observe September and October). In November reproduction is complete and no receptacles are found.

If you find a different pattern, for instance stage 1 occurring after stage 4, you may want to check to see if you are classifying the reproductive stages correctly.

What do scientists look for in the data?

Scientists are interested in learning how the reproductive cycle changes from year to year and if there is a long-term trend in when the reproductive phases occur. Scientists want to know what are the differences between the east and west of the North America, between the eastern and western Atlantic and what are differences among areas with similar water temperature. As well, scientists want to explore relationships with other hydrological measurements such as water temperature and salinity, and atmosphere measurements such as air temperature.



Seasons and Phenology

Introduction

Seasons*

S1: What Can We Learn About Our Seasons?*

Students develop a qualitative understanding of the characteristics and patterns of seasons and highlight the relationship of seasons to physical, biological and cultural markers.

S2: What Are Some Factors That Affect Seasonal Patterns? *

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

S3: How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?*

Students use GLOBE visualizations to display student data on maps and to learn about seasonal changes in regional and global temperature patterns.

S4: Modeling the Reasons for Seasonal Change*

Students use color visualizations and a 3-D paper model of the Earth to explore the causes of seasons, with a focus on Earth's tilt and its spherical shape.

S5: Seasonal Change on Land and Water*

Students use visualizations to compare the effects of incoming solar energy in the two hemispheres, furthering their understanding of seasonal change and climatic effects of land and water.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

*Phenology**

In Phenology Learning Activities, students have the opportunity to explore the effect of environmental changes on plants. They also practice basic science process skills such as quantitative and qualitative observation, inference, measurement, prediction, classification, data collection, analysis, and interpretation, and designing and carrying out an investigation.

*P1: Green-Up Cards **

students participate in a preparatory activity that will help them identify green-up progression in their local plants and this activity also introduces the idea of spatial scale related to plant observations.

*P2: A Sneak Preview to Budburst **

Students learn what to look for during budburst by observing variations in timing and appearance of leaves of different local plant species.

*P3: First Look at Phenology **

Students observe and classify local plants based on their patterns of change other than growth.

*P4: A Beginning Look at Photosynthesis**

Students learn about plant response to light by setting up simple investigations in the classroom.

*P5: Investigating Leaf Pigments**

Students learn about plant pigmentation and photosynthesis while conducting simple investigations to demonstrate the presence of pigments other than chlorophyll in leaves.

*P6: Global Patterns in Green-Up and Green-Down**

Students use visualizations and graphs to investigate the annual cycles of plant growth and decline associated with various land cover types.

*P7: Limiting Factors in Ecosystems**

Students learn about the physical factors that limit the growth of vegetative ecosystems by correlating graphs of vegetation vigor, temperature, and precipitation.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction

Summary of Learning Activities

In *Seasons and Phenology,* students investigate the causes of seasons and their impact on the Earth system, and they explore the effect of environmental changes on plants. During these explorations, students practice basic science process skills such as quantitative and qualitative observation, inference, measurement, prediction, classification, data collection, analysis, and interpretation, and designing and carrying out an investigation. The concepts presented in *Seasons and Phenology* are reinforced through the use of visualization techniques that are important tools for four of the learning activities.

Seasons

There are six learning activities that focus on developing student understanding of seasons. In *What Can We Learn About Our Seasons?* students develop a qualitative understanding of the characteristics and patterns of seasons and highlight the relationship of seasons to physical, biological, and cultural markers. In *What Are Some Factors That Affect Seasonal Patterns?,* students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns. In *How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?,* students use GLOBE visualizations to display student data on maps and to learn about seasonal changes in regional and global temperature patterns. The activity *What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?* promotes collaboration among teachers during and after the GLOBE teacher training program. It also helps teachers and students learn how the protocols are interconnected and can support inquiry-based investigations.

The last two seasons learning activities use visualizations to enhance student understanding. One of the most important causes of seasonal changes across the globe is the orientation and orbit of Earth in relation to the sun. The spatial model that scientists have designed to explain their observations involves Earth's tilt and the way sunlight spreads across a sphere. Understanding how Earth's relationship to the sun gives us seasons requires an understanding of complex spatial relationships that change over time. In *Modeling the Reasons for Seasonal Change*, students explore these relationships with a 3-D model of Earth that they construct from paper. Aided by depictions of Earth's placement at the equinox and solstice seasonal events, and by simple modeling tools that represent the sun and sunlight as it spreads over a spherical surface, students are guided to an understanding of how the astronomical relationship affects the temperatures and length of day experienced by plants and animals. A color visualization of incoming solar energy offers another source of visual data; in this activity, multiple representations are used to promote coherent student understanding.

As various activities demonstrate, the physical relationship between Earth and the sun is not the only factor that affects seasonal change. In *Seasonal Change on Land and Water*, students use color visualizations and graphs to understand how, at a global level, the presence of large bodies of water (in Earth's Southern Hemisphere) or large land masses (in Earth's Northern Hemisphere) affects the seasons in those regions. By analyzing color visualizations of incoming solar energy and surface temperature, students see that temperature ranges are not entirely consistent with the seasonal pattern of incoming solar energy in the two hemispheres, a result of the difference in heat capacity of large bodies of water and large land masses. Through this activity, students can connect their own local experience of heat capacity and thermal inertia with seasonal differences at a global scale.

Phenology

The phenology learning activities can help students connect global seasonal patterns to global changes in vegetation. There are seven learning activities that focus on developing student understanding of phenology. In *Green-Up Cards,* students participate in an activity, preparatory to doing the phenology protocols, which will help them identify green-up progression in their local plants. This activity also introduces the idea of spatial scale related to plants. In *A Sneak Preview of Budburst,* students learn what to look for during budburst by observing variations in timing and appearance of leaves of different local plant species. In *A First Look at Phenology,* students observe and classify local plants based on patterns of change other than growth. In *A Beginning Look at Photosynthesis* students learn about plant response to light by setting up simple investigations in the classroom. In *Investigating Leaf Pigments,* students learn about plant pigmentation and photosynthesis while conducting simple investigations that demonstrate the presence of pigments other than chlorophyll in leaves.

The last two phenology learning activities support student analysis through the use of visualizations. While students experience seasonal change mainly in the form of weather and daylight changes (more or less rain, different temperatures, longer or shorter days) and react to these changes by adapting their dress, vegetation undergoes more dramatic and predictable changes that can be studied at a global level using remote sensing. In *Global Patterns in Green-Up and Green-Down*, students investigate the annual cycle of plant growth and decline using color visualizations and graphs. They analyze data on the annual cycle of plant growth/decline and temperature. They find patterns of annual change for the globe and for each hemisphere. Students further explore these patterns in several regions that have different land cover.

After examining the relationship, at a regional level, between seasonal change and green-up/green-down, students can do the *Limiting Factors in Ecosystems* learning activity to understand that physical ecological factors—temperature and precipitation—limit the growth of vegetative ecosystems. Using graphs and color visualizations that show averages of vegetation vigor, temperature, and rainfall for different regions, students look for correlations across data to find potential limiting factors in vegetation growth.

Organization of Learning Activities

The learning activities are organized into two parts based on the focus of the activity: seasons or phenology. See pages 2-3 for a list and brief description of these activities.

Implementation Considerations

Sequence

In order for students to fully understand the reasons for the patterns of change they explore in the phenology learning activities it is recommended that they conduct some of the seasons learning activities first. Teachers can determine, based on the background of their students, which of these activities would most benefit their students. However, each activity is designed to be conducted independently of any of the other activities.

The phenology protocols ask students to gather some data that they may not be familiar with. Many of the phenology learning activities introduce the terminology and concepts required to do the phenology protocols properly. Therefore, it is recommended that some of the phenology learning activities be done before students begin to follow the phenology protocols. The protocols and the corresponding recommended learning activities are shown in the table below.

Design of Visualization Learning Activities

Each of the seasons and phenology learning activities that utilize visualizations (learning activities S5, S6, P6, and P7) has the same basic organization. First, the teacher provides background for students in a class discussion. Teachers often use this discussion period to elicit initial student ideas, linking the activity to students' experiences. Teachers may also decide to demonstrate the more difficult parts of the small group activity. Next, students break into small groups to further investigate the concepts, guided by a Work Sheet. During small group time, teachers move from group to group, facilitating the activity and checking for understanding.

Materials used in both the class discussion and small groups include the familiar diagrams, tables, graphs, and paper models. Perhaps less familiar to teachers are the use of color visualizations of global data. Against the background of an outline map projection, Earth systems data such as incoming solar energy, temperature, and vegetation vigor are represented as colors. These color visualizations are used to detect patterns in the data and to suggest questions that students can explore. The GLOBE *Earth as a System* poster has good examples of the type of color visualizations used in these activities.

After students have worked in small groups, the class comes together again to deliver their group results. Student assessment can be conducted through several means. One is the Student Work Sheet, for which rubrics are given. Another is the teacher observation of student work during small group time. Finally, students may demonstrate their understanding of the activity during their group presentation.

Relationship of Learning Activities to Protocols

Protocol	Learning Activity	Recommendation
Pre-green-up protocol	*Green-up Cards*	Required
Pre-green-up protocol	*Sneak Preview of Budburst*	Required
Pre-green-down protocol	*Cloud Estimation* (Atmosphere Chapter)	Required
Concurrent with green-up or green-down	*A First Look at Phenology* (refers to Land Cover Leaf Classification)	Strongly Recommended
Post-green-up or Post-green-down	*Beginning Look at Photosynthesis: Plants Need Light*	Recommended
Post- green-down	*Investigating Leaf Pigments*	Recommended

Alignment to Other GLOBE Learning Activities

Alignments for Seasons Learning Activities

The learning activities listed below reinforce the concepts presented in the seasons learning activities.

GLOBE Earth System Poster Activity Guide

This poster provides an excellent table that allows solar energy visualizations to be compared with visualizations of other variables, including average temperature, cloud cover, precipitation, soil moisture, and vegetation vigor. The *Activity Guide* will help students understand what they are looking at.

Atmosphere Investigation: *Making a Sundial*

Students construct a sundial and use it to observe the movement of the sun through the sky over the course of a day by marking changes in the position of the shadow once each hour. Students determine the approximate time of solar noon at their school as indicated by the time of the shortest shadow. Students revisit the site on a subsequent day to estimate the time of day using their sundial.

Alignments for Phenology Learning Activities

All the activities listed below reinforce the concept of phenology (response of plants to seasonal and climate change) and the interdependence of the different components of the Earth system.

Atmosphere Investigation: *Estimating Cloud Cover: A Simulation*

Students learn to estimate the percentage of cloud cover.

Land Cover/Biology Investigation: *Land Cover Sample Site Protocol*

Students learn to use a hierarchical classification system to assign a MUC class to their land cover sample sites.

Land Cover/Biology Investigation: *Odyssey of the Eyes: Intermediate, Advanced*

Students learn how a satellite sensor relays information to the computer.

Land Cover/Biology Investigation: *Leaf Classification*

Students learn to classify using leaves from their local environment.

Land Cover/Biology Investigation: *Site Seeing: Beginning*

Students use quantitative and qualitative observation techniques to investigate their 30 m x 30 m Study Site.

Hydrology Investigation: *Water Detectives*

Students use five senses to observe characteristics of water bodies.

Soil Investigation: *Just Passing Through*

Student examine the water holding capacity and filtering ability of soils with different properties which may affect plants.

Alignment for Use of Seasons and Phenology Learning Activities that Utilize Visualizations (S4, S5, P6, P7)

Four of the GLOBE *Seasons* and *Phenology Learning Activities* have students use color visualizations and other data to reason about causes, ask questions, and solve problems. Students will be taking a primarily global view of seasonal phenomena such as temperature, green-up, and precipitation. It is important that students understand how to relate the global and local. Therefore, a sample unit of instruction which can be found in the Teachers *Implementation Guide — Earth as a System: First Impressions Describing Earth,* will be useful activities in helping students connect the global phenomena they encounter with their experiences on the ground.

The seasons and phenology learning activities that use visualizations also rely on students' understanding how to interpret color visualizations. Therefore, the activities in the Atmosphere Investigation that focus on learning how to use visualizations in solving problems are useful. One is *Draw Your Own Visualization,* which teaches the basic components of a visualization; its purpose, the chosen color scheme, the data and units, and the underlying geography and scale. A second helpful learning activity is *Learning to Use Visualizations: An Example with Elevation and Temperature,* which employs color visualizations in problem solving. Students learn to identify important patterns in a color visualization. They also explore the relationship between two variables using color visualizations.

Student Learning Goals and Alignment with National Science Education Standards.

Student Learning Goals

The learning activities in the seasons and phenology section target aspects of science learning: content knowledge (particularly in the areas of seasonal change and phenology) and the skills of scientific inquiry.

In the seasons learning activities, students investigate regional temperature patterns and then look at the causes of seasonal change, considering issues such as Earth's tilt, its rotation around the sun, and resulting patterns in the incoming solar radiation as experienced in the different hemispheres. In the phenology learning activities, students are introduced to the basic concepts of budburst, photosynthesis, and pigmentation at the local scale; they look at relationships among ecosystems, environmental factors, and resulting patterns of green-up and green-down at the global scale.

Throughout the activities, students build skills in the use of the tools and processes of scientific inquiry. Many of the activities, for example, use *visualizations* as tools to support description and analysis of complex scientific data. Frequently, students are asked to investigate patterns using data from multiple sources or in multiple representations (ranging from color visualizations to graphs to physical models) and to draw conclusions based on their analysis. Students also develop skills in evidence-based reasoning and in presenting scientific arguments to their classmates.

Alignment with National Science Education Standards addressed by each of the Seasons and Phenology Learning Activities:

National Science Education Standards (NSES) offers valuable guidelines to teachers across the country. Such standards furnish teachers with what the science community currently believes are the important ideas in science, hopefully encouraging the exploration of connections and key concepts rather than the memorization of facts.

The following table indicates the particular National Science Education Standards addressed by each of the *Seasons* and *Phenology Learning Activities.*

Student Learning Assessment

Assessment rubrics are included at the end of many of the seasons and phenology learning activities. These can be used by the teacher to determine the extent to which students have understood the concepts and mastered the skills that were examined or used in the activity and to identify where there is still confusion. The assessments can also be used by students to help them reinforce what they have learned and to identify areas of weakness.

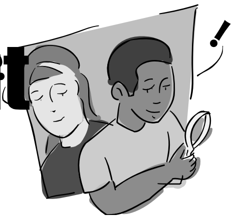
Coverage for Seasons and Phenology

National Science Education Standards	Learning Activity											
	S1	S2	S3	S4	S5	P1	P2	P3	P4	P5	P6	P7
Earth And Space Sciences												
Changes in Earth and Sky (K-4)												
Weather changes from day to day and over the seasons	■	■	■		■						■	■
Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis	■	■	■	■	■	■					■	■
Energy in the Earth System (9-12)												
The sun is the major source of energy at Earth's surface	■	■	■	■	■		■				■	■
Solar insolation drives atmospheric and ocean circulation	■	■	■	■	■		■					
Earth in the Solar System (5-8)												
Sun is major source of energy for phenomena on Earth's surface				■	■							
Geochemical Cycles (9-12)												
Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere)							■					
Physical Sciences												
Energy: Transfer and Conservation (5-8)												
Heat energy is transferred by conduction, convection and radiation		■	■		■							
Heat moves from warmer to colder objects		■	■		■							
Sun is a major source of energy for changes on the Earth's surface	■	■	■	■	■	■	■				■	■
Energy is conserved					■							
Chemical Reactions (9-12)												
Chemical reactions take place in every part of the environment							■			■		

Coverage for Seasons and Phenology *(continued)*

National Science Education Standards	Learning Activity											
	S1	S2	S3	S4	S5	P1	P2	P3	P4	P5	P6	P7
Life Sciences												
The Characteristics of Organisms (K-4)												
Organisms can only survive in environments where their needs are met							■				■	■
Earth has many different environments that support different combinations of organisms						■		■			■	■
Organisms and their Environments (K-4)												
Organisms' functions relate to their environment	■					■	■	■	■		■	■
Organisms change the environment in which they live	■	■				■	■					
Humans can change natural environments											■	■
Life Cycles of Organisms (K-4)												
Plants and animals have life cycles	■					■		■	■		■	■
Structure and Function of Living Systems (5-8)												
Ecosystems demonstrate the complementary nature of structure and function											x	x
Regulation and Behavior (5-9 & 9-12)												
All organisms must be able to obtain and use resources while living in a constantly changing environment	■					■	■		■		■	■
Populations and Ecosystems (5-8)												
All populations living together and the physical factors with which they interact constitute an ecosystem					■							
Populations of organisms can be categorized by the function they serve in the ecosystem						■					■	
Sunlight is the major source of energy for ecosystems	■	■	■	■	■	■	■				■	■
The number of animals, plants and microorganisms an ecosystem can support depends on the available resources					■	■				■	■	
The Interdependence of Organisms (9-12)												
Atoms and molecules cycle among the living and non living components of the ecosystem							■					
Energy flows through ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers)						■			■			
The population of an ecosystem is limited by its resources						■						
Humans can change ecosystem balance											■	■
Matter, Energy, and Organization in Living Systems (9-12)												
Energy for life derives mainly from the sun	■	■		■	■	■	■				■	■
Living systems require a continuous input of energy to maintain their chemical and physical organizations	■	■		■	■	■	■			■	■	■
The Behavior of Organisms (9-12)												
The interaction of organisms in an ecosystem have evolved together over time						■						

S1: What Can We Learn About Our Seasons?



Purpose

Students develop a qualitative understanding of the characteristics and patterns of seasons and highlight the relationship of seasons to physical, biological and cultural markers.

Overview

Students observe and record seasonal changes in their local study site. They establish that these phenomena follow annual cycles and conclude the activity by creating displays that illustrate the repeating pattern associated with the appearance and disappearance of seasonal markers.

Student Outcomes

Students will be able to,

- recognize aspects of seasonal change;
- explore relationships among seasonal changes;
- relate local seasonal changes to conventional equinox and solstice dates; and
- create a profile of local seasonal variation.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation.

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Life Sciences

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Plants and animals have life cycles.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

Sunlight is the major source of energy for ecosystems.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Observing seasonal changes

Recording observations in GLOBE Science Logs

Organizing observations in tables and graphs

Representing information with pictures, numbers, and photographs

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Use appropriate mathematics to analyze data.

Communicate results and explanations.

Time

On-going

One class period per month to visit the GLOBE study site; one or two additional class periods per month to record, graph, and discuss observations

Note: There is some advantage in designing a schedule for Study Site visits which corresponds to the data collection visits used in the protocols.

Level

All

Adapting the Activity to Different Levels:

Beginning: as described here

Intermediate: Discuss the strengths and weaknesses of qualitative data.

Advanced: Require more detailed observations of seasonal transitions. Also, discuss whether it is a coincidence that many cultural celebrations correlate with the solstices and equinoxes.

Materials and Tools

Large sheets of paper

Colored markers

Glue

GLOBE Science Logs

Preparation

Select and examine GLOBE Study Site.

Prerequisites

None

Background

The purpose of this activity is to engage your students in careful observations of the seasonal changes that occur in their GLOBE study site. Because we want them to be active participants in planning what they will observe, we ask them to predict which things they think will change in the study site. We then ask them to make careful observations and to compare these with their predictions. When they have collected observations over an extended period of time we ask them to identify trends in the phenomena and to predict "what will happen next" and why. In Step 6 we ask them to think about how the changes they observe are interrelated and in Step 7 to relate the observations to the conventional astronomical markers of seasons (solstices and equinoxes). The activity concludes by asking students to create a profile of each local season using their own observations and, if they wish, to share this with another GLOBE school using GLOBEMail.

We envision this as an activity that continues throughout the school year, with students adding observations on a periodic basis. As the teacher, you will need to decide how often students will visit the study site to make observations. If your site is readily accessible, you may be able to visit as often as once a week, especially during times of the year when many things are changing. But if this is not feasible, try to visit the site monthly. These visits can be supplemented by asking students to make observations near the school, looking out the window, at home, and as they travel to and from the school. If you keep separate records of changes observed at different local sites, you can discuss how the different sites compare.

Understanding what causes seasons is not the primary goal of this activity. Rather, it should be viewed as an introductory activity that focuses students on making careful observations, recording their observations in a systematic way, and noticing the annual cycles that their observations reveal. Remember that GLOBE is an international program and that seasonal changes are quite different in different parts of the world where GLOBE schools are located. This is a wonderful asset of the GLOBE program! We suggest that you contact a GLOBE school in another part of the world and share information with them on your seasonal observations.

Procedure

1. **Ask students to think about the seasons that occur in their GLOBE study site.**
   How would they characterize the local seasons? How many seasons are there? What are they called? When do they begin and end? Compose a description of local seasons that the class can agree on.

2. **Brainstorm about change.**
   Ask students to think about things that are likely to change in their GLOBE study site during the course of the year as the seasons change. Organize them in small groups and ask each group to make a list of all the changes they think might take place. One way to do this is to think

about how the study site will change during each month of the year. Guide them to think about changes such as:

- changes in plant life and vegetation, e.g. blossoming of trees and flowers, leaves dropping, grass turning brown, the appearance of certain fruits
- changes in animal behavior, e.g. birth of babies, hibernation, migration
- changes in personal behavior and societal behavior
- changes in the physical environment, e.g. getting warmer or colder, rainier or drier, freezing or thawing of bodies of water.

Have a whole-class discussion of all the changes that the small groups have recorded. Create a composite list for the entire class of changes that you think will occur in the study site during the course of a year.

3. Record actual observations.

The point now is to begin to observe systematically the kinds of changes that students listed in the preceding step. Help students develop an organized system of recording changes that they observe in the study site. If they have GLOBE Science Logs, they can record their observations there. But, in addition, they should record the observations in a form that can be displayed and viewed by the entire class for purposes of discussion. Particularly with younger students, the format should be large and easy to understand. One possibility is to use large sheets of chart paper, one paper per observation period. All the observations made during a given week or month can be recorded on a single large sheet of paper. The paper can then be hung in the classroom, attached to a bulletin board, or displayed in the hallway. As the students make other visits to the study site they can record their observations on separate sheets and add them to the display. The sheets can include sketches, leaves, blossoms, or buds collected (fastened on with glue), photographs the students took, numerical data they might have gathered, and “impressions” they might have recorded in prose or poetry.

4. Review the changes that have been observed in the study site.

Once the students have made some observations and recorded them, it will be valuable to review them in light of the lists produced in Step 2. Compare the actual observations with the expectations. As you accumulate data over time, discuss how the study site changes from one visit to another. What were the changes in vegetation, the water, the animals that live there, the moisture, the temperature, etc. Refer to the observations made during the previous visit to form comparisons. If the observations have been recorded on large sheets of paper, then it will be easy to refer to them during the discussion. Ask students to talk about what has changed and what has not changed. As a concluding activity, summarize the changes that have been observed. For younger students, the teacher can write down summaries of what the students say; older students might write a summary in their GLOBE Science Logs.

5. Predict and explain.

Ask students to predict, based on what they saw on this visit and the last, what changes they expect in the study site on the next visit. Ask them to think about what is happening in the study site, what is happening with the season. What trends do they see developing? Do they think the temperature will be colder or warmer next time? Will the site be wetter or drier? Will the vegetation be more leafed out or less? Whatever observations they are tracking, ask them to predict what they think the next period’s observation will bring. Ask them to explain why they expect the changes they predict. (This will also give you an insight into their reasoning process.) What do they think might be causing the changes they predict? Record these predictions on a large sheet of paper and keep it for comparison with the actual observations next time. You may also want students to record one or more predictions in their GLOBE Science Logs.

6. **Explore relationships among changes.** The changes that students are observing in their study site are not occurring in isolation. They are interrelated parts of seasonal change. Ask students to think about and discuss the possible relationships among the phenomena or parameters that are changing. Ask them to discuss, for example, how changes in air temperature are related to changes in animal behavior; how changes in moisture in the ground are related to changes in plants that are growing in the ground. Look for as many relationships as possible. Ask students to explain why they think these phenomena are related to each other. As a class, write down why you think these things are related. Also ask students to write about these relationships in their GLOBE Science Logs.

7. **Relate the observations to the conventional seasons.** The summer and winter solstices and the vernal and autumnal equinoxes define the conventional seasons. Explain to students that these are special days in the annual calendar, and that they are marked as the longest and shortest days and the days that have equal amounts of daylight and darkness. Ask students to think about the condition of their study site in relation to these divisions of the year. What changes do they observe that might coincide with these astronomical markers? Using the data they collect, ask students to see where they think each season actually "should" begin and end. Ask them to think about whether there are any easily defined, sharp markers of the beginning and end of each season.

8. **Create a profile of your seasons.** As a culminating activity, ask students, perhaps working in small groups, to create a profile of each local season based on the observations they have made. (This activity may have to wait until you have collected sufficient data.) Ask the students to characterize not only the "height" of a season but also the transition points between seasons. Ask them to think about how the observed phenomena mark the beginning, the height, and the end of each season. Consider whether the seasons begin abruptly or gradually. For example, in monsoon areas, the onset of the first monsoon rain is sudden, followed by a more gradual drop in temperature. Consider sharing the profiles you create with another GLOBE school through GLOBEMail.

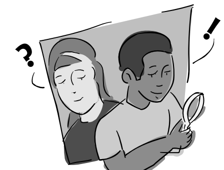
Assessment

- Ask students to select one aspect of the study site that they have studied, such as trees, and to describe how trees change in the study site over the course of a year. The description could be pictorial, graphical, verbal, or kinesthetic.
- Give students observations of one aspect of the study site (such as the air temperature) from two or three months of the year (such as November and December) and ask them to predict what the observation would be like in the month following and preceding the observed months (October and January). This asks them to be able to identify a trend and its direction.
- Give students the observations from a "mystery month" and ask them to tell what month they think it was and why. If it is too difficult to pinpoint the exact month, ask them to identify the season in which they think the observation was made.

Extensions

- If students are comfortable with graphical representation of data, they can create graphs showing certain study site conditions. Current temperature and precipitation would be particularly appropriate.
- Contact another GLOBE school using GLOBEMail and share your observations with them. Ask them to send you their observations at their study site. Look at their observations and try to predict how their site will change at the next observation. Compare your prediction with what they send you next.
- Investigate how seasons are portrayed in art, literature, and history. How, for example, were the seasons expressed in painting by the French Impressionists? How have seasons affected the outcomes of military battles, such as the siege of Leningrad? How are seasons portrayed in Shakespeare's plays and poetry? How did Thoreau describe the seasons in *Walden*? How are the seasons described in the *Little House on the Prairie* series of

S2: What Are Some Factors That Affect Seasonal Patterns?



Purpose

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

Overview

Students analyze the graph of the past year's maximum and minimum temperatures at their site. They compare this graph to similar graphs for two other sites - one nearby and one distant. They list factors that might cause the patterns to be different, and select one to investigate in depth. They repeat this process with other parameters. Students summarize their investigations by describing how latitude, geography and elevation influence seasonal patterns.

Student Outcomes

Students will be able to:

- Interpret a graph of annual temperature data;
- Identify factors that account for temperature pattern differences;
- Compare temperature patterns on a regional basis.

Science Concepts

Physical Sciences

- Heat energy is transferred by conduction, convection and radiation.
- Heat moves from warmer to colder objects.
- Sun is a major source of energy for changes on the Earth's surface.

Earth and Space Sciences

- Weather changes from day to day and over the seasons.
- Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.
- The sun is the major source of energy at Earth's surface.
- Solar insolation drives atmospheric and ocean circulation.

Life Sciences

- Sunlight is the major source of energy for ecosystems.
- Energy for life derives mainly from the sun.
- Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

- Graphing GLOBE data to show seasonal patterns
- Comparing graphs and analyzing data to determine the effects of latitude, elevation and geographical features
- Drawing conclusions about which factors can influence seasonal patterns
- Generating questions and developing hypotheses
- Designing and conducting an investigation
- Develop explanations and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicating conclusions to others

Time

(assuming 45 minute classes)

Day 1	Steps 1-3
Day 2	Steps 4 and 5
Day 3	Steps 6-9
Days 4 and 5	Steps 10 and 12
Extension	Step 11

Level

Intermediate and Advanced

Materials and Tools

Wall map of the world

If computers are unavailable or limited in number, print outs of the graphs in Steps 1, 4 and 6

Computer and access to the GLOBE Web site

GLOBE Science Logs

Preparation

Post a wall map of the world.

Assemble necessary data for students to plot.

Prerequisites

Students should understand that insolation levels vary with latitude, and that latitude has a powerful influence in determining seasonal conditions and the annual patterns of environmental and climatic parameters such as precipitation and temperature. For a more complete discussion, read *The Seasonal Picture: Why Are There Seasons?* in the *Introduction* to *Earth As a System Investigation.*

Crosswalks to Other GLOBE Learning Activities

See Earth as a System Investigation: Using Graphs to Show Connections for another good graphing exercise in which students construct graphs of air, soil, and water temperatures. Student graphs are then interpreted and interconnections explored.

Procedure

Step 1. Using the GLOBE graphing tool, have students plot the past year's maximum and minimum temperatures for their site on a single graph. See Figure EA-S2-1.

Step 2. To highlight the general temperature trends, have students use one of the following ways to draw a line through the middle of the plot of the maximum and minimum temperature measurements.

a. have each student draw the lines directly on a copy of the graph.

b. have students lay a clear sheet of acetate over a copy of the graph and draw the lines onto the acetate with overhead markers.

Note: Because temperatures can fluctuate dramatically from day to day, a plot of daily temperatures can look very jagged. Furthermore, since the GLOBE graphing tool connects each data point with a line, the resulting graph has a great deal of "noise", marks that add little real information. In most cases, however, it is the long-term trends that enable students to make the most meaningful comparisons. By drawing a line approximately through the center of each plot, students can determine a rough average for each set of measurements and highlight the long-term trends. See Figure EA-S2-2.

Once students draw an "average line," they can superimpose it on other "average lines." For example, students can superimpose an "average line" of the minimum temperatures at their site onto the plot of their site's maximum temperatures to see if both temperatures rise and fall in the same way. Also, students can examine temperature patterns from different years by superimposing the "average lines" of the maximum and minimum temperatures from one year on a similar graph from another year. Students can also see how trends at different sites compare by superimposing

Figure EA-S2-1: The plot of a GLOBE site's maximum and minimum temperature data generated by the graphing tool

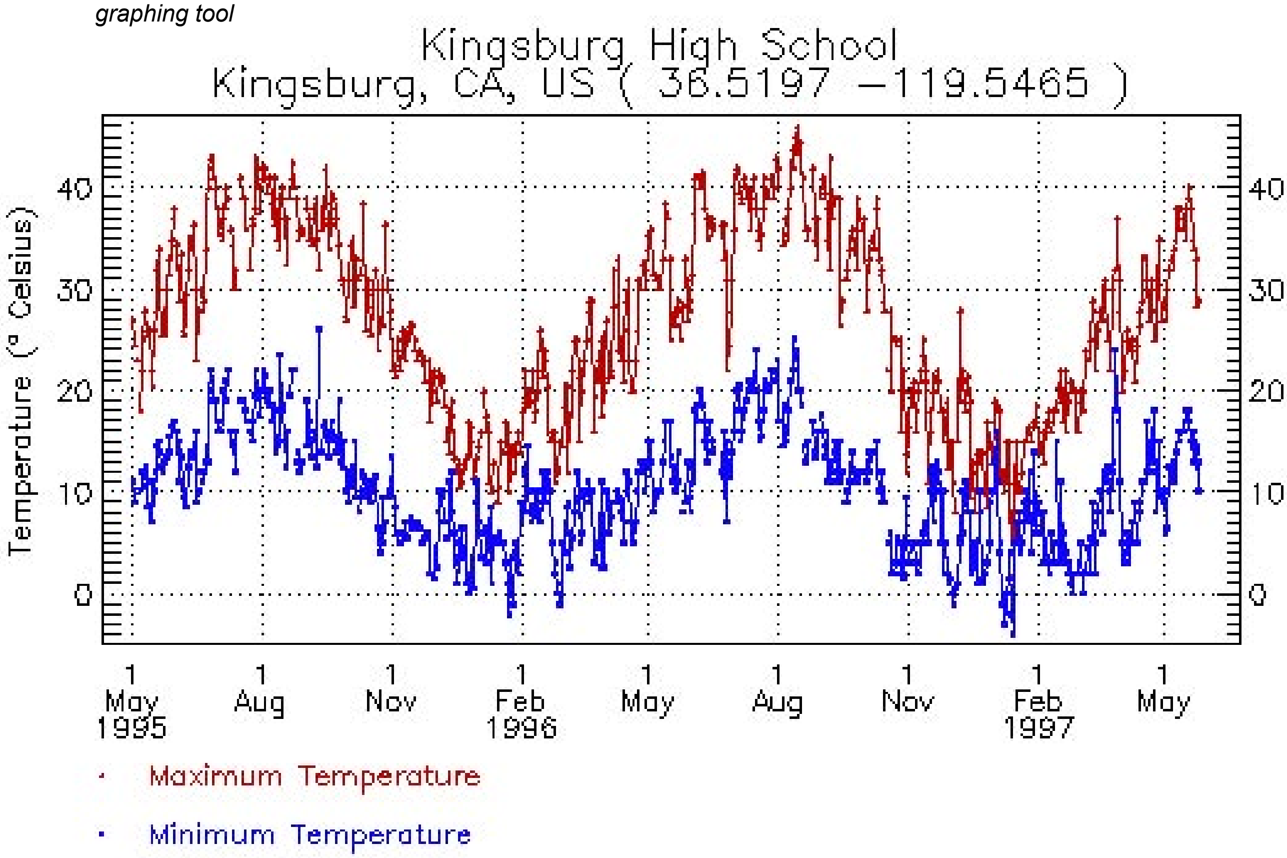


Figure EA-S2-2: Two "average lines" drawn through a plot of a GLOBE site's maximum and minimum measurements.

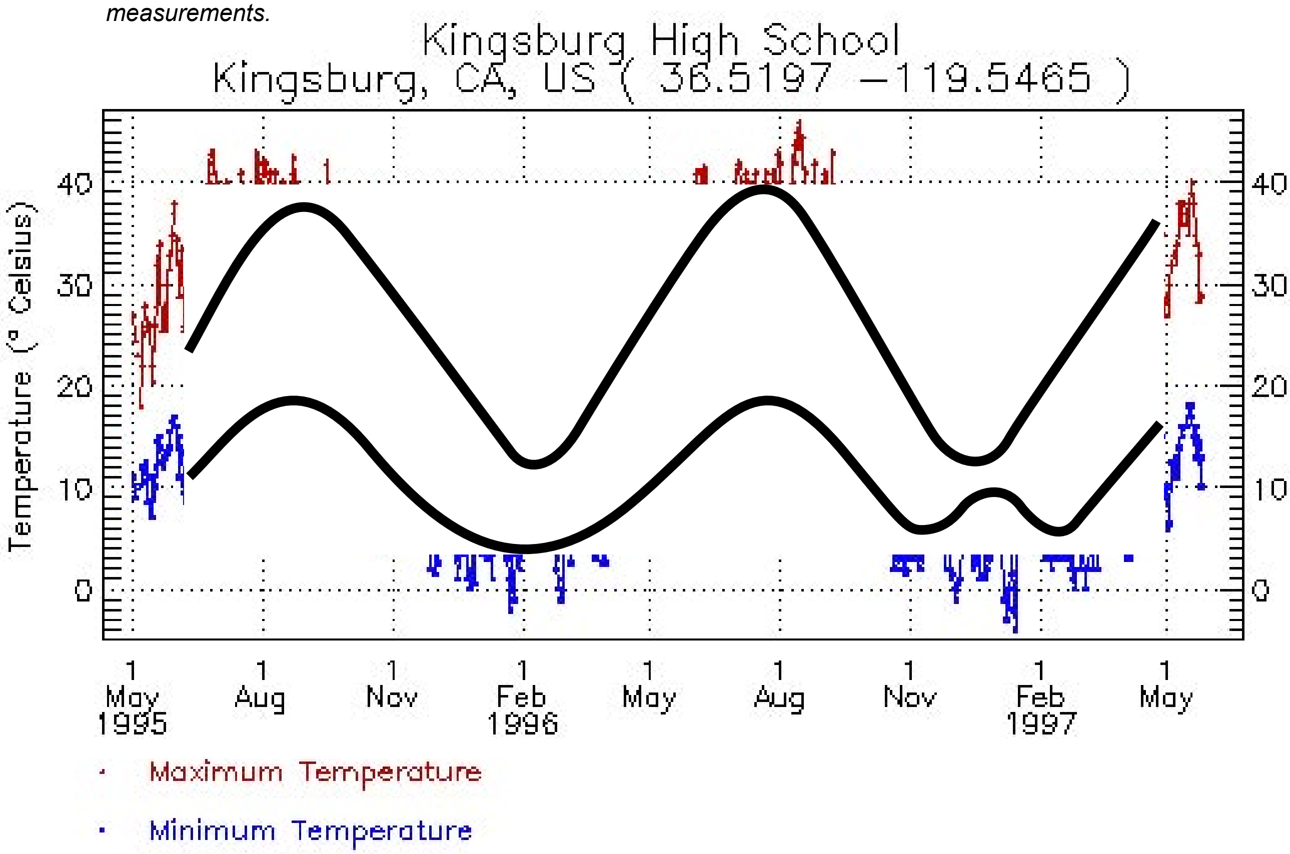
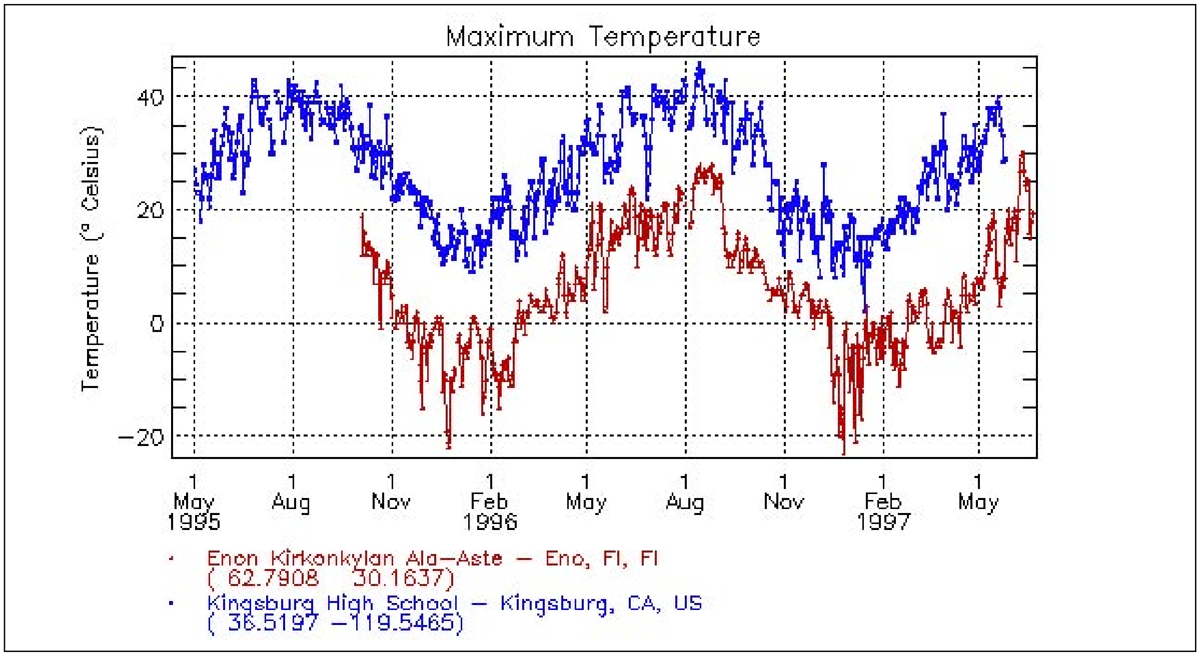


Figure EA-S2-3: The maximum temperature plot from GLOBE sites in Finland and California generated by the graphing tool. Note that the California site has reported data over a longer time period.



the “average lines” from one site onto the plot of the temperatures at another site.

Step 3. Have students analyze the graph of these data by considering questions such as:

- What is the general shape of the average line?
- What does the shape of the average line enable us to say about our site?
- What is the approximate difference between the daily maximum and minimum temperatures throughout the year? How does this difference vary over the year?

Note: This analysis can be conducted as a class discussion. If the graph is printed for each student, it can also be done in small groups or assigned as homework. Have students copy or paste the graph into their GLOBE Science Logs and record their analysis and any questions that arise.

Step 4. Have students find another GLOBE school about 100 km away and repeat Steps 1-3 for this school.

Note: This step asks students to find a school at approximately the same latitude as theirs (100 km north or south is roughly equivalent to 1° of latitude). Climatic changes happen gradually unless there is some dramatic elevation or geographic change over a short distance. As a result, by analyzing the data from a nearby school, students are likely to see similar temperature patterns. When there are differences, their knowledge of the local geography should help them pinpoint reasons for the differences, such as one site is coastal and the other is inland, one site is at a higher elevation than the other, or one site is behind a mountain range.

This step builds students’ graph-analysis skills by having them compare graphs with only a few significant differences. Also, because they are familiar with the local geography, this step increases the likelihood that students will identify key factors that influence temperature patterns. By pre-selecting a nearby site with sufficient data, you can greatly expedite this step.

Step 5. Have students describe how the temperature patterns at the nearby site are similar to and different from theirs. For each difference they observe, have students suggest reasons that might explain such variations. After students work together in small groups, conduct a class discussion that summarizes the comparison. Possible points of comparison include:

- How does the timing of the year’s maximum and minimum temperatures compare?
- How does the spread between daily maximum and minimum temperatures compare?
- How do the general shapes of the graph lines on the two graphs compare?
- What conclusions about seasons can be drawn based on the temperature patterns at these two sites?
- Do the temperature levels change similarly after the solstices and equinoxes?

Note: To facilitate comparisons, the graphing tool can be used to plot one parameter such as maximum temperature for two sites. See Figure EA-S2-3. If graphs are printed for each student, this step could be done in small groups or assigned as homework. Have students sketch or attach print outs of the two graphs and record their analysis and any questions that arise in their GLOBE Science Logs.

Step 6. Have students choose another GLOBE site at least 1000 km away that is likely to be climatically different. Have them repeat Steps 1-5

Note: The intention of this step is to find a GLOBE site with an annual temperature pattern quite different from the two already considered. The analysis could be assigned as homework.

Step 7. Have students list factors that might cause the patterns to be different.

Note: Use a wall map of the world or the maps found under GLOBE Visualization to focus attention on differences in latitude and elevation, and in proximity to oceans and other significant geographic features. Have students record the factors and any questions that arise in their GLOBE Science Notebooks.

Step 8. Since every site has a combination of factors, conduct a class discussion based on the Venn diagram shown in Figure EA-S2-4. In their GLOBE Science Logs, have students write a general statement about how latitude, elevation and geography influence their local temperature patterns.

Note: Students should understand that it is important to know a site's latitude, elevation and geography before drawing conclusions about its temperature patterns.

Step 9. Ask each group to select one of the factors that might account for temperature pattern differences between the distant site and theirs. Have group members write a plan for investigating this factor, including how to use GLOBE data to test their hypotheses. For example:

<u>Elevation:</u> Compare the annual temperature patterns of sites at different elevations.

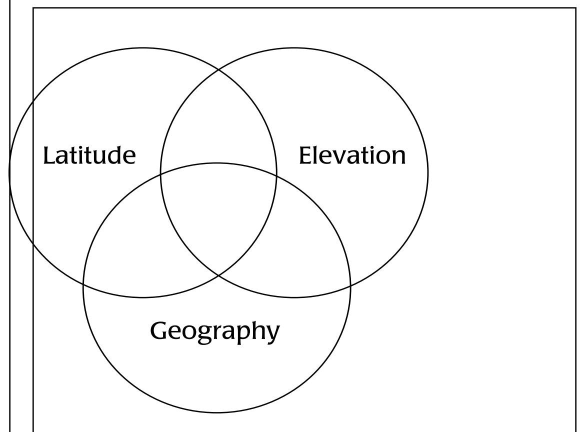
<u>Latitude:</u> Compare the annual temperature patterns of sites at different latitudes.

<u>Coastal versus Inland:</u> Compare the annual temperature patterns of sites at different distances from oceans — where do the effects of a marine climate end? They might also compare the marine effect along different coasts.

Note: Different coasts can have different marine effects. For example, the Atlantic and Pacific coasts of the U.S. have different current patterns and prevailing winds that result in different kinds of marine climates. However, both these marine climates moderate temperature extremes and provide considerable moisture to the air.

<u>Additional Factors:</u> Many parts of the world have factors that pertain only to a local region. For example, students could compare sites near to and far from the Gulf Stream, the Santa Anna winds, the Sahara Desert, the Amazon basin, coastal mountain chains, rain shadows, and prairies.

Figure EA-S2-4: Every site has a combination of factors that influences the annual patterns of its



Also, they could investigate what kind of influence the size of a continent and the direction of the prevailing winds can have.

Note: To confirm the influence of one factor, students will have to keep all other factors constant. For example, to see if elevation has an effect, students must find sites that differ in elevation but have similar coastal-continental locations, latitudes, and proximity to significant geographical features. If the only difference in the sites is elevation, then any differences in temperature patterns can be ascribed to elevation. To bolster confidence in any pattern they find, students will also need to use data from several sites and from a significant time period (e.g., a year). An effect seen by comparing data from only two sites or from a single day is vulnerable to errors and short-term changes and is very unreliable. Have students record their hypotheses and procedure in their GLOBE Science Logs.

Step 10. Have students follow their plan and summarize any effects they discover.

Note: Have students record their data, analysis and conclusions in their GLOBE Science Logs. They can share their investigation, conclusions and further questions with another school (such as the ones selected for comparison) using GLOBEMail.

Step 11. To further investigate how these factors influence seasonal patterns, have students repeat Steps 1-10 using precipitation and any other parameters they deem important in characterizing a season.

Note: For a mini-investigation in how to determine whether one parameter such as temperature influences another such as precipitation, see *How Can One Tell Whether Two Parameters Are Interrelated?* in the *Appendix*.

Step 12. In their GLOBE Science Logs, have students write statements about:

a. how latitude, elevation and geography influence the seasonal patterns of the parameters measured in the GLOBE program; and
b. how the annual patterns of the parameters measured in GLOBE are interrelated.

Assessment

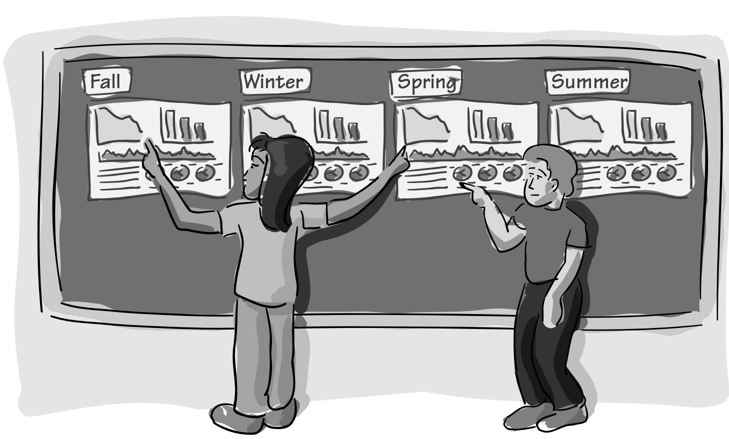
By the end of this activity, students should be able to use graphs and data to support the claim that seasonal patterns are influenced by a combination of latitude, elevation and geography.

All Levels

Poster reports, papers, and multi-media and oral presentations require that students organize and prioritize their thoughts and present their understanding coherently. Consequently, they are effective techniques for assessing students' mastery of concepts, skills and processes. The quality of the information recorded in their GLOBE Science Logs is also an important component in assessing students' ability to communicate their science. Examine their log entries, and have them use their GLOBE Science Logs to develop their reports and presentations.

Have students demonstrate their understanding of how latitude, elevation and geography influence seasonal patterns by having them respond to questions such as:

- Why are patterns at our site so similar to those at the site 100 km away?
- Why are there such differences between our site and the one 1000 km away?
- What factor(s) did you investigate, how did you do it and what did you conclude?
- Discuss how latitude, elevation and geography influence each parameter measured in GLOBE.
- What are some geographical features that influence seasonal patterns in our area? Describe how they influence the patterns and use data to support your claim.
- How can there be distant sites that experience patterns similar to ours while at the same time there are other distant sites that experience patterns different from ours?



- When considering latitude, elevation and geography, does one seem to be more important than the others in determining local seasonal patterns?
- What would you want to know about a site before commenting on its seasonal patterns? Explain why such information is important.
- Why is temperature alone a poor indicator of a season?

  Note: Temperature is variable over the short term and is influenced by other variables such as latitude, elevation and geography. For example, summer at the poles can still be cold and spring at the base of a mountain is different from spring at its summit. One needs to know a location's latitude, elevation and geography to understand the seasonal patterns.

Advanced

- How would the graphs of a site change were it moved to a different latitude, elevation or geographical setting?
- Provide students a graph of an annual pattern that is inconsistent with that pattern at their site. Students should be able to identify specific ways the "mystery" pattern is different from theirs.

  Note: You could draw a hypothetical pattern or use one from another site.
- How do seasonal fluctuations relate to the timing of the solstices? Equinoxes? How soon after the solstices do changes begin to occur? Is the lag time the same for each season? For each solstice?

  Note: Temperature levels are influenced by the energy available from the sun. Because the solstices are the dates that correspond with insolation extremes in the temperate and polar zones, the solstices represent points in a temperature's annual cycle in these zones. However, it takes time for the atmospheric temperatures to respond to these insolation extremes, so there is a lag time of several weeks before the new levels of insolation have a significant affect on temperature. In this activity, students will discover lag times as they check whether temperature levels in the temperate and tropical zones change on the date of the solstices. Because sites have different latitudes, elevations and geographical settings, different sites will have different lag times. Note that on the equinoxes, the sun is directly over the equator. Consequently, the equinoxes represent the insolation extremes in the tropical zone.

S3: How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?

Purpose

Students use GLOBE visualizations to display student data on maps and to learn about seasonal changes in regional and global temperature patterns.

Overview

Students use the GLOBE Student Data Archive and visualizations to display current temperatures on a map of the world. They explore the patterns in the temperature map, looking especially for differences between the Northern and Southern Hemispheres, and between equatorial regions and high latitudes. Then students zoom in for a closer look at a region which has a high density of student reporting stations (such as US and Europe). They examine temperature maps for the region, from four dates during the past year (the solstices and equinoxes). Students compare and contrast the patterns in these maps, looking for seasonal patterns. At the end of the activity, students discuss the relative merits of different types of data displays: data tables, graphs and maps.

Student Outcomes

Students will be able to:

Summarize the effect of latitude, elevation, and geography on global temperature patterns;

Explore local and regional seasonal variations.

Science Concepts

Physical Sciences

Heat energy is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation.

Life Sciences

Sunlight is the major source of energy for ecosystems.

Scientific Inquiry Abilities

Mapping data with the GLOBE Student Data Server to explore seasonal temperature patterns

Comparing graphs, maps and data tables as tools for data analysis

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

Approximately three 45-minute class periods

Level

Intermediate and Secondary

Materials and Tools

Access to the GLOBE Data Server

A map of the world

Acetate and markers (optional, so students won't mark directly on maps)

Preparation

Make copies of local, regional, and national maps

Post a large map of the world

Prerequisites

We recommend that students first do *What Are Some Factors That Affect Seasonal Patterns?*, which will give them experience using graphs to explore seasonal changes and basic understanding of factors affecting seasonal changes in temperature.

Crosswalks to Other GLOBE Learning Activities

See *Atmosphere Investigation: Making a Contour Map* to prepare students for constructing their own regional or local temperature maps.

Earth as a System Investigation: Your Regional to Global Connections to introduce the factors of wind patterns and ocean currents to you global analysis of temperature and seasonal changes.

Background

In this activity, your students use GLOBE's visualization tools to explore seasonal patterns in global and regional temperature data. This serves two purposes. First, students learn about seasons in a global context. Second, students learn how to use GLOBE's mapping tool to see global patterns in GLOBE student data.

Special Note: Some regions do not yet have enough reporting stations for thorough analysis.

For the time being, there are regions of the world (such as the United States and Europe) which have large numbers of schools reporting data, whereas other regions have fewer stations. Therefore, when you look at GLOBE visualizations, you will find some areas of the world with ample data for the types of analyses described here, whereas other areas may be too sparse for adequate analysis. Recognizing this temporary constraint, this activity includes both global studies (using the full scope of GLOBE reporting schools) and regional studies (which focus on areas with many reporting sites). Eventually, as GLOBE grows, your students will be able to do more and more global studies.

Mapping Data with the GLOBE Visualization Tool

Please refer to the color maps displayed in Figure EA-S3-1 through EA-S3-8. GLOBE's visualizations display student data in maps. These visualizations are especially powerful tools, and can be used to help students conduct a variety of investigations. In essence, you select the region that you want displayed, the type of data, and a date and time. Then the GLOBE software creates the requested map, and sends it to you over the Internet.

There are two types of maps that can be displayed:
dot maps and contour maps

Figure EA-S3-1 is a point map. This shows each reporting school as a colored dot. The color of the dot corresponds to the value reported by the school. This type of map is best when you want to know where the reporting schools are located, and get a sense of the individual data values (as represented by the color).

Figure EA-S3-2 is a contour map. This map uses the raw data to create contours, such as the temperature bands in the example. This type of map is best when you want to explore patterns in the data. You can use the color key to find out what values are indicated by each band. Also, there may be regions of the map without contours. These are areas in which there are no reporting stations.

For these activities, we recommend contour maps because we are more interested in the patterns than in the actual values. Your students will focus primarily on the shape of the temperature bands (noting, for example, where a given band dips down toward the equator).

Your students may quickly learn how to work with contours, since these are the same types of temperature maps that appear in newspapers and on TV, and appear in science textbooks. If your students are confused, you might want to have them work with a point map to make their own contour map. First, use crayons to circle all the points in each temperature range (for example, use red to circle all points with a temperature of 20-29, blue for temperatures 30-35, etc.). Then have your students use crayons to draw bands connecting the points that are the same color.

Temperatures Vary from One Location to Another Around the World

Your students begin by displaying current temperatures, as reported by students around the world. For example Figure EA-S3-3 shows a map of student data from all currently reporting schools. In the activity, you will have students explore the map, looking for global patterns. In this example, notice that:

1. There are gaps in the data, because some parts of the world do not yet have GLOBE schools. The world coverage will improve over the years.
2. Since the data are from December, the Northern Hemisphere is generally cooler than the Southern Hemisphere
3. There are variations in the temperature patterns based on current weather and local climatology (e.g. France is warmer than Northeastern U.S., even though they are both at the same latitude)

Regional Maps Show Greater Detail in the Temperature Patterns

When you zoom in for a closer look at a region of the world, you can see more detail. This enables you to see regional patterns more clearly. In Figure EA-S3-5 through EA-S3-8, you can see the differences among four different views, each representing a different season. For example:

1. Temperatures are generally warmer in the summer than the winter.
2. Weather patterns are not constant throughout the year (for example, the curves in the temperature contour on June 21 is not the same as on Sept. 21).

Your students can extend the investigation by looking at seasonal variations in other types of data, such as precipitation type and amount, soil moisture or water temperature. Your students can also explore how the local variations are affected by local geography and elevation.

Temperature Patterns Vary from One Season to the Next

When your students display temperature maps from four different days throughout the year, they are able to explore the seasonal variations in global temperatures, as shown in the above sample maps. (For more detailed analysis, your students could display data from each month of the year).

In these sample maps, Figures EA-S3-5 through EA-S3-8, notice that:

1. It is generally warmer in the summer and colder in the winter.
2. Fall and spring are similar in temperature.
3. Regardless of season, it is warmer the farther south you look.

What To Do and How To Do It

Note: These activities work best if students gather around the computer or take turns, so that they can work directly with the GLOBE visualizations. Or you can print the GLOBE maps and make copies for each student or for groups of students.

Step 1. Display a map of recent temperatures world-wide.

Use the GLOBE data system to access recent temperature data (either minimums or maximums) from all student sites around the world, and display the data on two types of maps: point map and contour map. You might want to choose yesterday's data, since some schools may not yet have reported today's data.

Step 2. Students explore the global temperature maps.

Begin with the point map. Have your students examine the map. First look for your own site. This shows the temperature data reported by your school. It is shown as a colored dot, with the color corresponding to the temperature. Next, look for other sites, and compare their location and temperature with your own. Find other schools with the same temperature (color) as your own. Find other schools in your own country. Find a school in each continent. Then find the absolute warmest location, and the absolute coldest location.

As noted in the background section, you will see that some areas have many GLOBE schools reporting data, and other areas have few or none. As more schools begin reporting data, your students will be better able to see global patterns. You can use this opportunity to help your students see the importance of having many schools world-wide and having each report their data every day.

Next, have your students look for global patterns in the temperature data. Your students might notice that:

1. Temperatures are warmer in equatorial regions, and colder as one moves further north or south.
2. The Northern Hemisphere is warmer than the Southern Hemisphere or vice-versa.

Step 3. Students zoom in for a local view, and explore regional seasonal variations.

Ask your students what they think the global temperature map will look like at different times of the year. This can be a useful discussion, helping students to think about global seasonal patterns, and to make their own predictions. It also helps you as teacher to find out what your students know and what misperceptions they might have.

Tell your students that they will now zoom in for a closer view of one or more regions of the world. Have them select areas of the world where there are many data points, and then request a contour map for that region. Make sure your students understand what the contour map shows (same data as in the data map, but presented as temperature bands). Ask them what shapes and patterns they see in the contour map.

Now select maps of the same region, from four different dates during the year. This will enable them to examine how the temperature patterns change over the year. Ask your students what four days would best represent the four seasons of the year. Discuss your students' suggestions. Either proceed with whatever dates they suggest, or guide the discussion to selecting the four seasonal transition points (June 21, Sept. 21, Dec 21, Mar 21). You might want to discuss the significance of these dates (solstices and equinoxes). Another approach is to select 12 dates, one per month. This will give your students more detail in the year-long variations.

Access, display (and if possible print and make copies of) the temperature map for each of the four days.

Now have your students study the maps. What similarities do they see from one season to the next? What differences? You want to promote student inquiry and investigation here, so don't simply tell them what the patterns are, but let your students explore the maps and discuss individually or in small groups.

Discuss what they found. They are likely to see:

1. One season tends to be warmer than another.
2. Regardless of season, it tends to be warmer as one moves closer to the equator.
3. Weather patterns are not constant throughout the year. The shape of the temperature bands will vary from one day to the next.
4. If you look at schools in the same latitude, you will find differences in their temperatures.

Ask your students why these patterns occur. For example, they may understand that the Northern and Southern Hemispheres have opposite seasons. Or they may comment that local weather conditions have an impact on the seasonal variations (coastal regions tend to have more stable temperatures throughout the year).

Step 4. Students compare and contrast data tables, maps and graphs. See Figure EA-S3-9 through EA-S3-11.

In this activity your students use GLOBE maps. In other activities, students use graphs and in

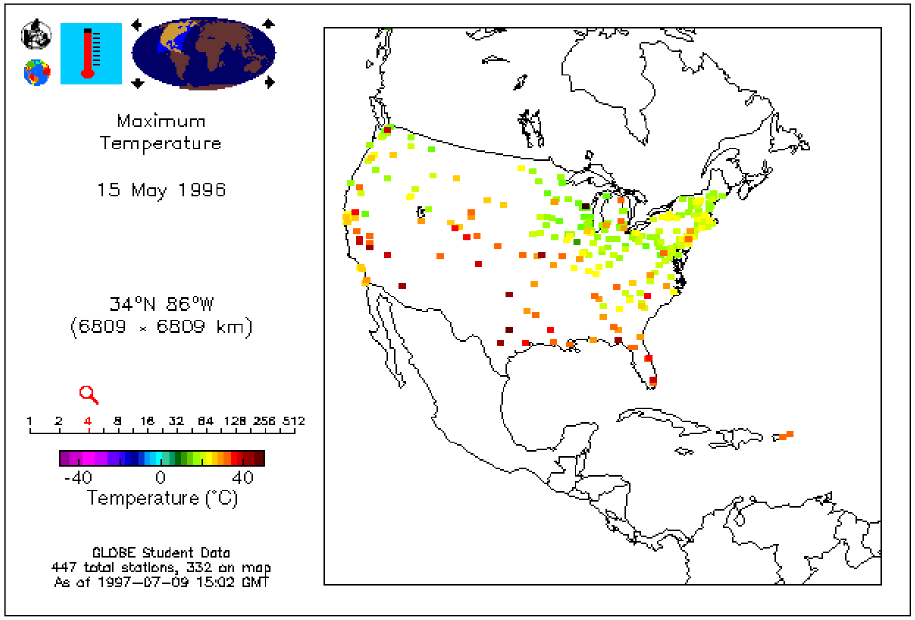


Figure EA-S3-1: GLOBE Dot Map of Maximum Temperatures in the U.S., on May 15, 1997

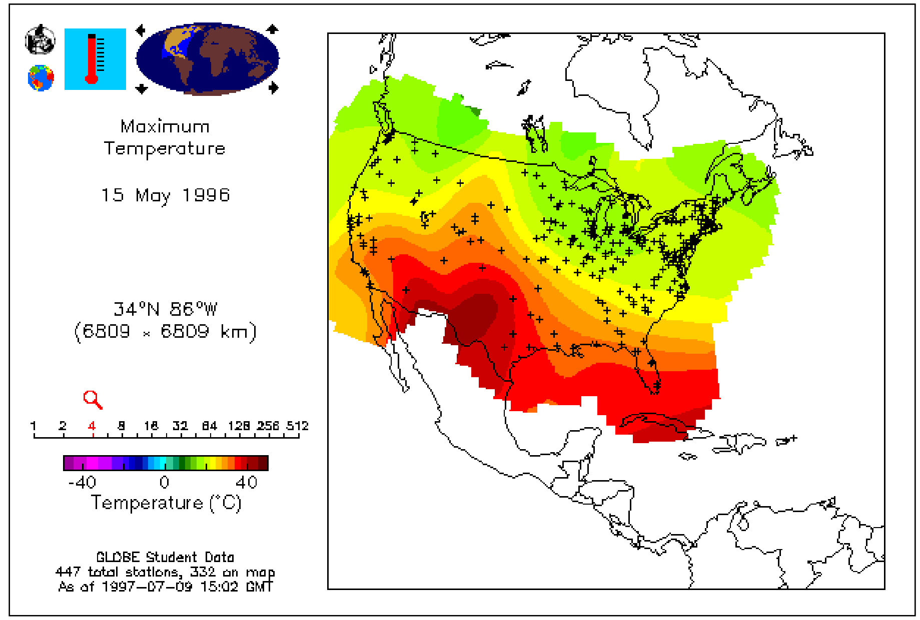


Figure EA-S3-2: Same GLOBE Data as a Contour Map

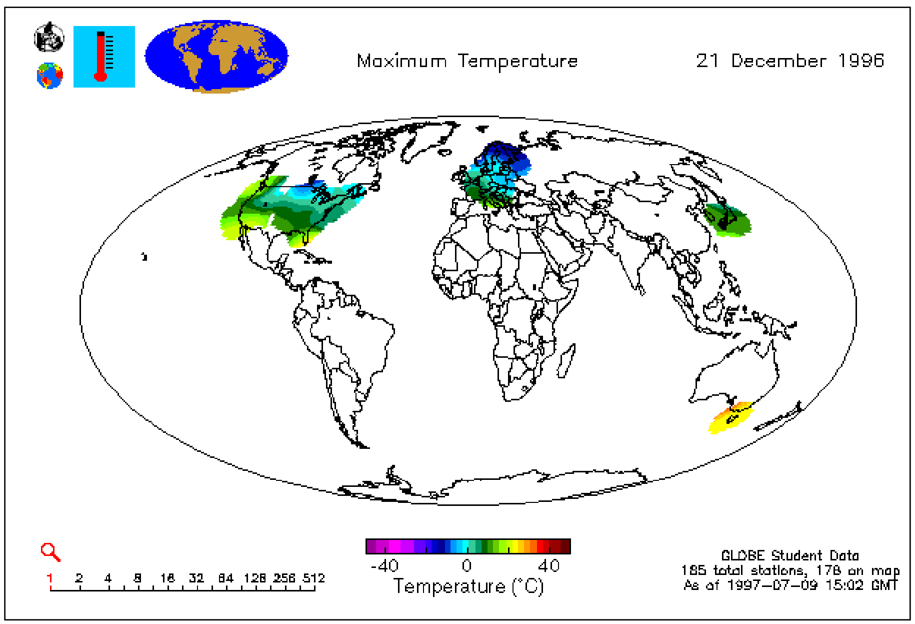


Figure EA-S3-3: World Temperature Patterns on December 21, 1996 (These maps will become more complete as additional GLOBE Schools begin submitting

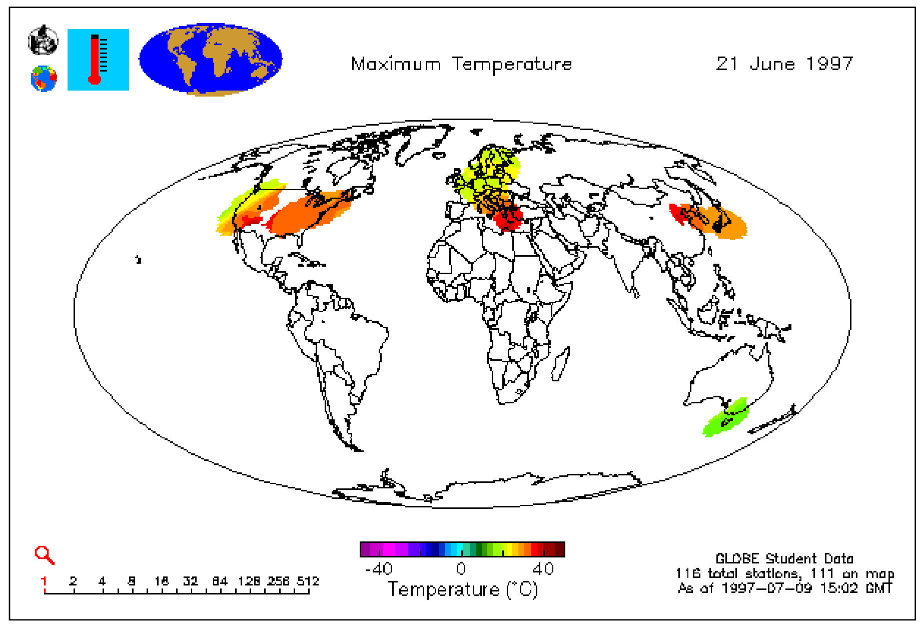


Figure EA-S3-4: World Temperature Patterns on June 21, 1997

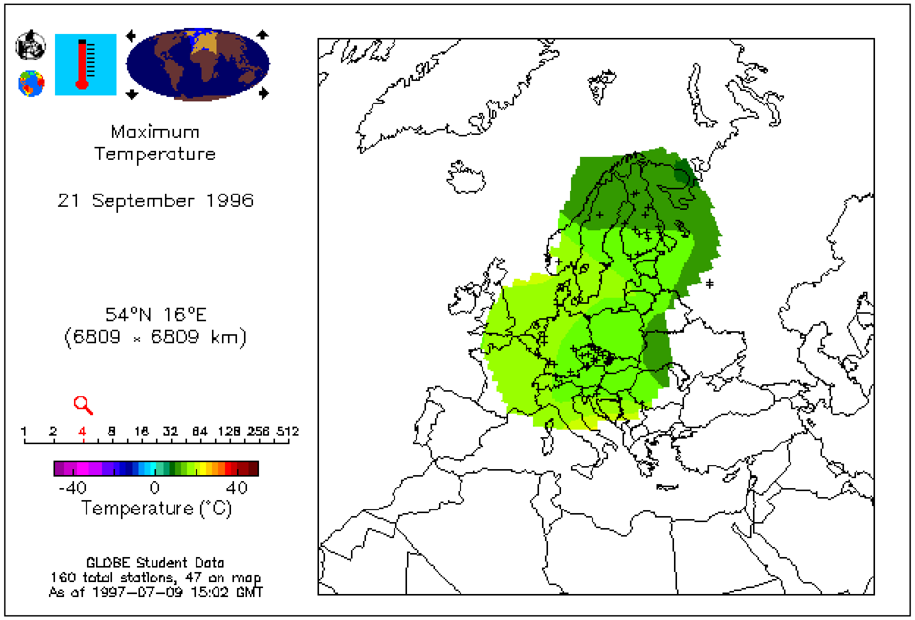


Figure EA-S3-5: Europe Temperatures in the Fall - September 21, 1996.

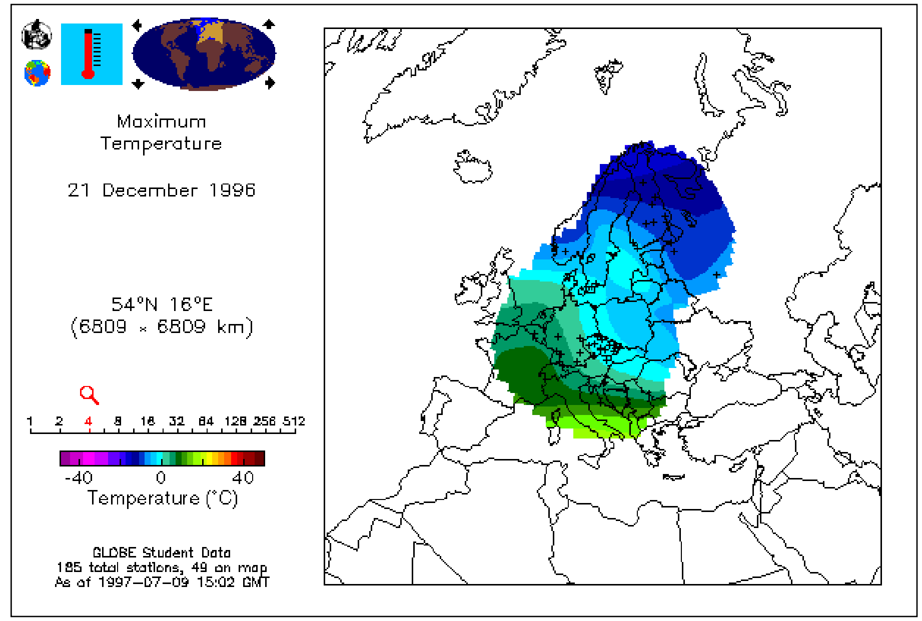


Figure EA-S3-6: Europe Temperatures in the Winter- December 21, 1996.

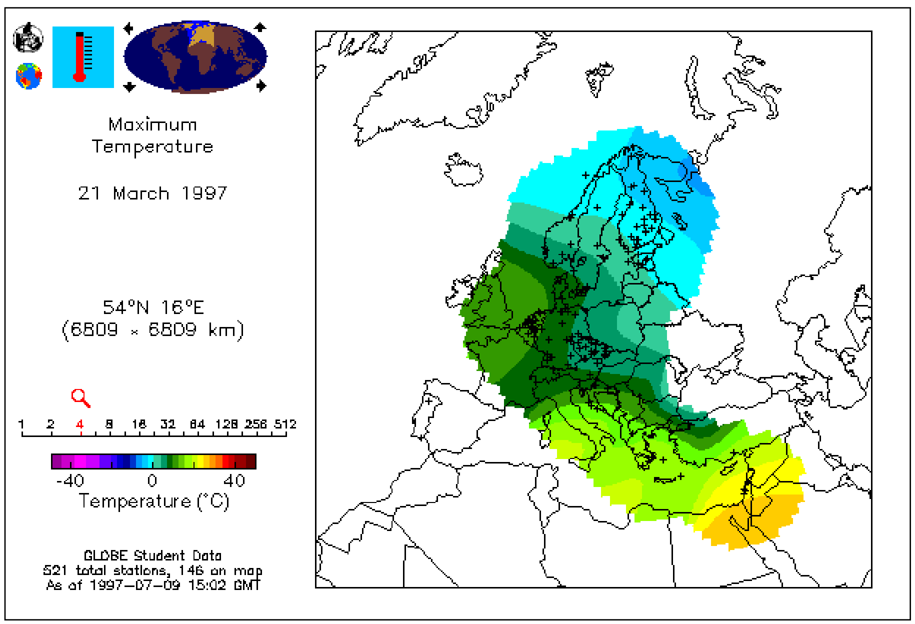


Figure EA-S3-7: Europe Temperatures in the Spring - March 21, 1996.

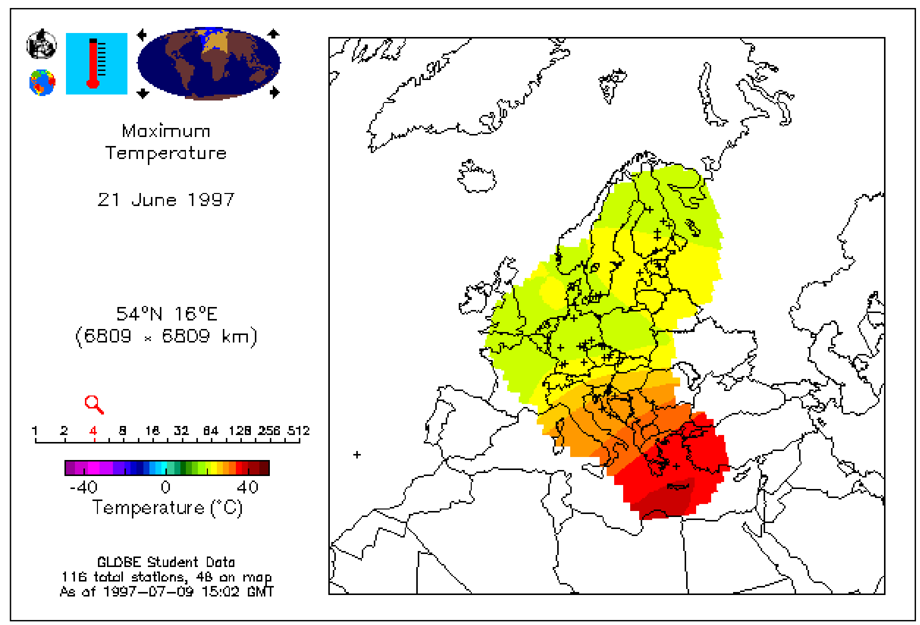


Figure EA-S3-8: Europe Temperatures in the Summer - June 21, 1996.

Figure EA-S3-9: Maps

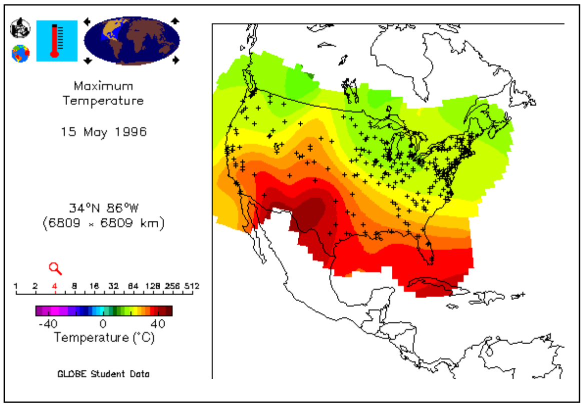


Figure EA-S3-10: Graphs

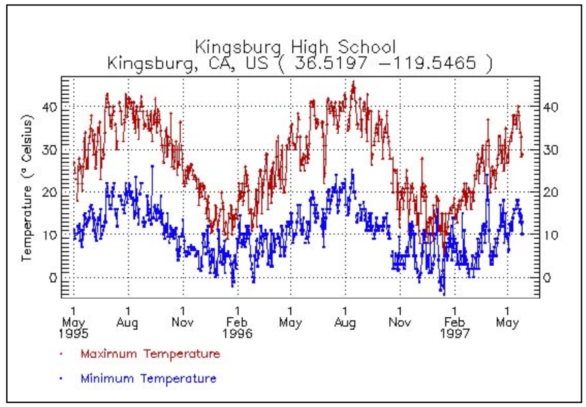


Figure EA-S3-11: Data Table

Data for 19970707 to 19970707

Atmospheric Temperature						TEMPERATURE		
MG	YY/MM/DD	HR	LAT	LONG	ELE	CURR	MAX	MIN
AT	97/07/07	20	47.6589	-117.4250	675	24.0	34.0	12.0
AT	97/07/07	19	32.2217	-110.9258	836	36.1	41.7	25.6
AT	97/07/07	19	36.5197	-119.5463	27	34.0	39.0	17.0
AT	97/07/07	19	33.7769	-118.0386	7	24.0	24.5	17.0
AT	97/07/07	19	45.4556	-112.1961	1594	29.0	29.0	7.0
AT	97/07/07	18	33.7769	-118.0386	7	23.0	26.0	16.0
AT	97/07/07	18	40.7608	-111.8903	1711	29.0	34.0	16.0
AT	97/07/07	18	47.6064	-122.3308	67	21.0	-99.0	-99.0
AT	97/07/07	17	57.7883	-152.4030	35	12.0	15.0	11.0
AT	97/07/07	17	35.8422	-90.7042	69	31.0	31.5	17.5
AT	97/07/07	17	39.7683	-86.1581	259	28.0	-99.0	-99.0
AT	97/07/07	17	39.2403	-76.8397	57	30.0	-99.0	-99.0
AT	97/07/07	17	44.8817	-69.4458	88	28.0	30.0	7.5
AT	97/07/07	17	39.7558	-77.5782	375	27.0	27.0	16.0

others they use data tables. These three types of data displays enable your students to visualize, understand and interpret the data. At this point, it is worth exploring with your students the merits and applications of these three types of data displays.

Show your students these three types of data displays. Ask your students what type of information they see in each display. Then discuss with your students the advantages and disadvantages of each type of display.

For example, your students might notice that:

Maps show how data varies from one location to another. You can see world-wide or regional patterns such as the warmer temperatures in the equatorial regions of the world.

Graphs show how data changes over time. You can see annual patterns such as the warmer temperatures in summer and the colder temperatures in winter.

Data tables show lots of data values in a grid. You can quickly find any type of data for any location, such as the temperature and precipitation amount for a given city.

Post a copy of the map, graph and data table on a bulletin board, and have your students write under each type of display some interesting observations that they see in that display. For example, under the graph they might write the coldest day of the year. Under the map, they might write the coldest location in the world. Then have them write some questions that could be answered with that type of display.

You may need to revisit this comparison of different types of data displays, as students plan their own investigations, such as in step 5 below. Students need to be sure that they're using the most appropriate display for their data analysis.

Step 5. Students use an inquiry-based approach to extend the investigations.

There are several ways that you and your students can extend the investigations. For example:

- Print out maps from two consecutive days (such as June 21 and June 22). Using these two maps, students can explore short term variations versus long-term seasonal changes. For example, they might see minor changes in the shapes of the temperature bands from one day to the next, and larger changes in the overall temperatures from one season to the next.
- Pick two locations for more detailed comparison. For example, your students might find that a town on the Mediterranean coast has less variation between winter and summer than a place in central Canada. This might be because the water of the Mediterranean has a moderating effect on temperature variations. If so, do other coastal locations have similarly moderated temperature variations?
- Display other data on the maps, such as precipitation amount. Students might compare patterns of snowfall in the winter versus the summer and compare Northern Hemisphere vs. Southern Hemisphere.

In each of these extensions, be sure your students use an inquiry-based approach, in which students:

1. Begin by exploring the displays to see what patterns and questions emerge.
2. Select a question that seems especially interesting.
3. Decide what resources can help students investigate the question. Especially focus on use of GLOBE data (each of the examples above uses GLOBE data).
4. Conduct the investigation, either individually or in teams.
5. Share the findings with other students.
6. Think about what new questions emerged that could lead to further investigations.

For these investigations to succeed, they need to be genuinely engaging for the students, the student(s) should really care about the answer. One goal of the activities in this seasons module is to stimulate such interests. In that sense, these activities not only have their own intrinsic value, but also serve as launching pads for further investigations.

Assessment

In this activity, your students have learned about seasonal patterns in global temperature data. They also have learned about GLOBE's map visualization tools. To assess student learning, use the following two steps:

1. Ask your students to use the GLOBE data server to create a contour map of student temperature data from July 15 and January 15 (these dates are near the peaks of summer and winter, and are different from the maps they've already used). Check to make sure each student is able do this activity correctly. You might have a student who knows how to do this help you by observing the other students as they go through the steps, to see who knows how to do this, and who has what kinds of problems.
2. If possible print out the July 15 and January 15 maps from the previous step, and make copies for your students. If you can't do this, then use the sample Dec 21 and June 21 temperature maps that appear in the background section. Then have your students indicate which is summer and which is winter. If you wanted to extend the assessment further, you might print out a 6 month sequence from July 15 to January 15 (one map from each month), cut out or cover over the date on each display, and then ask your students to sort them into the proper sequence. Then ask them to write down what evidence they used to put them in this sequence.

S4: Modeling the Reasons for Seasonal Change

Purpose

To understand what causes the Earth's seasons, with a focus on the Earth's tilt and its spherical shape

Overview

Students learn how sunlight spreads over the Earth at different times of the year, emphasizing the solstices and the equinoxes. Students investigate the effect of the Earth's tilt on the spread of sunlight by modeling different tilts using a three-dimensional polyhedron which they construct from paper. Students calculate the relative sunlight intensity received by the Northern and Southern Hemispheres to understand seasonal differences between the hemispheres.

Student Outcomes

Students can correctly explain how the Earth's tilt causes seasons.

Students can interpret the effect of different scenarios of Earth's tilt on the seasons and global climate.

Students can use color visualizations and spatial models to understand phenomena and solve problems.

Science Concepts

Earth and Space Sciences

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation.

Sun is a major source of energy for phenomena on Earth's surface.

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Life Sciences

Sunlight is the major source of energy for ecosystems.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Modeling and analyzing three-dimensional relationships that vary in time

Analyzing patterns in color visualizations

Assembling a three-dimensional model from a flat plane

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Use appropriate mathematics to analyze data.

Communicate results and explanations.

Time

Two-three 45-minute class periods

Level

Middle, Secondary

Materials and Tools

Globe (if not available, any sphere such as a ball can be used)

Overhead projector and transparencies for class discussion

Paper copy of the three-dimensional polyhedron to assemble, a copy of the sunlight circle and protractor page, a pair of scissors, and tape for each group

Preparation

Photocopy grid (Figure EA-S4-3) onto an overhead transparency.

Assemble a three-dimensional polyhedron from the paper template.

Divide students into groups of 2-3.

Prerequisites

Students should be familiar with the use of color visualizations. *Learning to Use Visualizations: An Example with Elevation and Temperature* and *Draw Your Own Visualization Learning Activities*, in the *Atmosphere* chapter, are recommended.

Background

Most places on the Earth experience seasonal variation during the year: in different areas it may be hot, cold, rainy, or dry depending on the season. Length of daylight can vary as well: latitudes near the poles experience nearly 24-hour sunlight at the peak of summer and nearly 24-hour darkness at the peak of winter. Around the world, people, plants, and animals are adapted to the types of seasonal variation experienced in their own region.

What causes the seasons? Seasonal changes, including temperature and length of daylight, indicate that the sun's light received by the Earth varies both throughout the year and at different latitudes. But the reasons can be difficult to understand.

The first explanation many people give for seasonal change is that the sun is at different distances from the Earth at different places in its elliptical orbit. It seems to make sense that it would be summer when the Earth is closer to the sun and therefore receiving more of the sun's energy, and winter when it is farther away; after all, you do feel warmer when you sit closer to a fire. But how would this explain the fact that seasons are opposite in the Northern and Southern Hemispheres and much more extreme at higher latitudes than at the equator?

The biggest reason for seasons is actually the *tilt* of the Earth. This, coupled with the Earth's *spherical shape,* impacts the intensity with which sunlight is received at different latitudes and at different times of the year. Since the Earth's tilt is not something we can directly experience, its effect is easier to understand using visualization techniques. In this activity, you will use color visualizations and three-dimensional models to learn how the Earth's tilt and its spherical shape make the seasons occur.

First, here are some important concepts:

1. The Earth receives energy from the sun in the form of insolation.

Scientists call the energy coming to the Earth from the sun *insolation* (INcoming SOLar radiation). This energy gives Earth both heat and light. As the Earth spins each day on its *axis* (the invisible straight line running through the North and South poles), the side facing the sun receives direct insolation and therefore experiences daytime - sunlight and warmer temperatures - while the side of the Earth facing away from the sun experiences night.

2. The Earth is tilted by about 23.5° as it rotates around the sun.

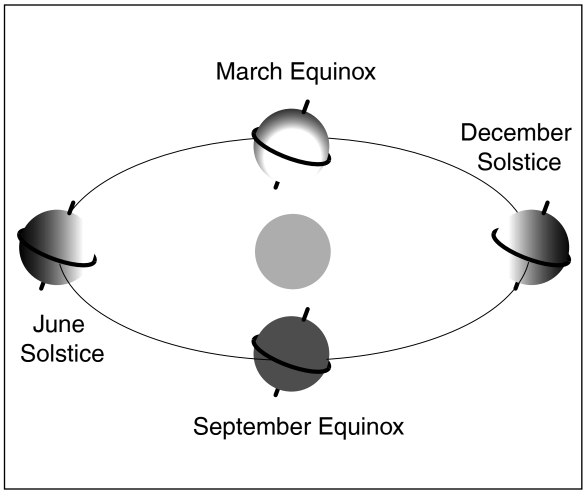
As the Earth makes its yearly revolution around the sun, it does not "stand" straight up. In other words, the Earth's axis is not exactly vertical. Scientists explain this mathematically by saying that the Earth is tilted about 23.5° off of the plane in which it orbits around the sun.

3. The tilt of the Earth stays constant as it orbits the sun.

The Earth's tilt affects the amount of insolation particular latitudes on Earth receive from the sun. For example, at some times during the year the North Pole is inclined towards the sun (see Figure EA-S4-1, June solstice), and at other times it is inclined away (see Figure EA-S4-1, December solstice). Let's look at this effect at two important times of the year: an *equinox* and a *solstice.*

Equinox (equal night). We experience the vernal and autumnal equinoxes as the two days each year when the length of day and night are equal for every place on Earth. In the Northern Hemisphere, the vernal (spring) equinox occurs around March 21 and the autumnal (fall) equinox

Figure EA-S4-1: Effect of Earth Tilt



The distance between the sun and the Earth remains essentially constant throughout the year. The tilt of the Earth also remains constant. At the solstices, the hemisphere that is tilted toward the sun experiences summer.

is around September 23. In the Southern Hemisphere, the two are reversed: March 21 is the autumnal equinox, and September 23 is the vernal equinox.

At these times, the two hemispheres receive equal amounts of insolation from the sun. Look at Figure EA-S4-1. At the equinoxes, sunlight illuminates the two hemispheres evenly. If you were looking at the Earth from the sun's point of view, you would be able to see the same amount of each hemisphere, centered on the equator. This is why, at an equinox, the same length of daylight is experienced by each of the hemispheres.

Solstice (stand still). Solstice is the time when one hemisphere experiences its longest day and the other experiences its shortest. It occurs two times each year, on June 22 and December 21. The word "solstice" comes from "sol" meaning "sun" and "stice" meaning "stand still." This is because the sun appears to stand still as it reaches its highest point at midday (in summer) or lowest (in winter).

A solstice happens because of tilt. In Figure EA-S4-1, look at the picture labeled December solstice. In this case, the North Pole is tilted away from the sun, so that even as the Earth revolves around its axis the North Pole never receives direct sunlight. Meanwhile, the South Pole is tilted toward the sun, so it experiences its longest day of the year. In the June solstice, the opposite occurs: the North Pole is tilted toward the sun, and the South Pole is tilted away.

4. Energy from the sun spreads unevenly over the Earth due to its spherical shape.

If the poles have 24-hour-long days during their summer, why are they so much colder than the equator? The reason is that the *intensity* of sunlight is not the same at every point on Earth. Sunlight is spreading over a sphere, not a flat surface. If the Earth were a two-dimensional circle that always faced the sun, it would receive an equal amount of energy at every point. But because the Earth is spherical, the same amount of sunlight that hits 1 square meter of Earth where the sunlight is perpendicular covers a much greater area elsewhere on Earth, where it hits the Earth at a shallower angle.

5. Insolation is strongest where sunlight strikes the Earth at a 90˚ angle to the Earth's surface.

At any given time, the Earth receives the most direct insolation at the latitude where sunlight strikes at a perpendicular angle. As the angle at which sunlight strikes the Earth changes from 90˚, the same amount of energy is spread over a greater area, so the energy per unit area decreases.

At an equinox (see Figure EA-S4-1), sunlight strikes the Earth at a 90˚ angle at the equator. At a solstice, where the Earth is tilted away from or toward the sun, sunlight strikes the Earth most directly at one of the tropic latitudes (23.5˚ N or 23.5˚ S).

In the activity that follows, you will use a physical model to explore how the Earth's tilt and spherical shape impact the amount and intensity of light received at a given latitude, which in turn causes seasonal change.

What To Do and How To Do It

In this activity, students explore the effect of the Earth's tilt using a three-dimensional model, estimating how different tilts would change the relative amount of insolation falling onto the Northern and Southern Hemispheres during different seasons.

1. Ask students for their initial ideas about the causes of seasonal change.
2. Conduct a class discussion to introduce the important concepts of the Earth's tilt and how sunlight spreads across the spherical Earth.
3. Introduce the student activity using a paper icosahedron (20-sided polyhedron) as a model of the Earth.
4. Student teams each assemble an icosahedron.
5. Working in small groups, students use their models and *Work Sheets* to compare expected seasonal effects of several scenarios of Earth tilt: no tilt, actual tilt (23.5˚), and greater than actual tilt (45˚).
6. Analyze results as a class.

This activity can be conducted in either 2 or 3 class periods. Following is one suggested breakdown, using two and one-half periods:

- Conduct step 1 at the end of one class period and assign students to read the *Background* section as homework.
- Complete steps 2-4 in the second period and steps 5-6 in the third period.

Step 1. Solicit Initial Student Ideas.

Open the topic of seasonal change with a discussion of observable seasonal differences in your geographic area, and solicit ideas from students about what causes those changes to occur. Since seasonal change is so closely linked to people's experience in most climates, many students will already have ideas about what might be the cause. List these and discuss them; you may also want to revisit the list at the end of the activity to see how beliefs have changed. Several common intuitive ideas follow:

- *Because of the elliptical shape of its orbit, the distance between the Earth and the sun varies over the course of the year.* It is seems logical to believe that summer happens when the Earth is close to the sun, and winter when it is farther away. Questions to consider: are seasons the same in both Northern and Southern hemispheres (as implied by this model)? The Earth is relatively close to the sun at two points in its orbit; why do we not experience two summers a year?
- *The Earth's tilt causes seasons.* If students suggest this cause, probe further. Frequently the underlying belief is still related to relative distance from the sun: the hemisphere tilted closer to the sun will experience summer because the sun's rays are stronger with increased proximity. Other students may believe that the Earth's tilt "wobbles", which causes seasonal fluctuations.

Step 2. Introduce Concepts of Tilt and the Spread of Solar Energy Over the Globe.

This introduction has three parts:

- Introduce color visualizations of seasonal changes.
- Use a globe to illustrate the effect of Earth's tilt as it orbits the sun.
- Use an overhead projector to illustrate how insolation spreads over the Earth.

1. Introduce color visualizations of seasonal changes.

Using a color overhead or copy of Figure EA-S4-2, orient students to this global visualization of incoming solar energy at the various latitudes during the solstices (June and December) and equinoxes (March and September). Observations:

- The maximum energy is close to 500 watts per square meter – the equivalent energy of five 100-watt light bulbs for every square meter – and the minimum is 0 watts.
- The equator receives much more solar energy, year round, than the poles: an effect of the spherical nature of the Earth, as will be demonstrated shortly.
- The distribution of insolation across the two hemispheres is roughly opposite at the solstices, where one hemisphere experiences winter while the other

experiences summer. This is an effect of the Earth's tilt (pictured in Figure EA-S4-1). The effect of tilt will be demonstrated next.

2. Use a globe to illustrate the effect of Earth's tilt as it orbits the sun.

For this demonstration, use a globe or (if a globe is not available) a ball with the equator and poles marked. The globe should be held at approximately a 23.5° clockwise tilt; most globes already have this orientation.

This demonstration will show how sunlight received at various places on Earth changes as the Earth orbits the sun. Students in the class represent the "sun," and "cast their light" on the parts of the globe that they can see. (When issues of tilt get confusing, thinking about a view of the Earth from the perspective of the sun can be a good tool.) If the configuration of your classroom makes this demonstration difficult, you can "orbit" around a single student sitting in the front of the class, and ask the student to describe what is seen.

- Stand at the front of the class, hold the globe straight up, and then tilt it 23.5° clockwise for students to see. This models the equinox in September. Students (in their role as the sun) should be able to see both poles clearly, and have equal views of the Northern and Southern hemispheres. You may want to spin the globe on its axis, to model the rotation of the Earth each day.
- Now, *without changing the tilt of the globe,* move to your right 1/4 of the way around the room. *It is important for you to face in the same direction as you circle the classroom.* The Earth has completed 1/4 of its orbit, and you are now modeling the December solstice. Now students should have a better view of the Southern Hemisphere. The South Pole is pointed toward them, so they can see the pole even as you spin the globe (at the peak of summer, the sun never sets at the pole). By contrast, the North Pole is pointed away so that even as the Earth turns on its axis, students will never have a clear view of the North Pole.
- Complete your "orbit" by moving to the back (March equinox) and left side (June solstice) of the room, always facing in the same direction as you circle.
- Return students' attention to Figure EA-S4-2. Did this demonstration shed any light on the reasons for the distribution of incoming solar energy for each of the global orientations pictured?

3. Use an overhead projector to illustrate how insolation spreads over the Earth.

Earth's tilt explains seasonal variation between the two hemispheres, but does not explain the differences in sunlight intensity between latitudes in the same hemisphere. Point again to Figure EA-S4-2: why are the areas above and below the tropics consistently cooler than the area around the equator?

The reason is that sunlight spreads unevenly across a sphere. To demonstrate this, use an overhead transparency of a grid. See Figure EA-S4-3. On this grid, each square represents a constant unit of the sun's energy.

- First project the image from the overhead directly onto a flat wall or screen, oriented to minimize distortion. The cells projected on the wall should be the same size and shape. If the Earth were flat, all areas of the Earth that are "visible" to the sun at any given time would receive the same intensity of insolation.
- Now project the image from the overhead onto a globe or ball. The light spreads unevenly over the curved surface of the globe so each cell shows as a different size. This means that one "unit" of solar energy is spread over a larger area at higher latitudes.
- The squares should be smallest (indicating the highest intensity of insolation) where the light is shining exactly perpendicular to the globe. If the globe is held straight, this point of greatest light intensity is the equator.

- Return to the visualizations in Figure EA-S4-2, and ask students to interpret the figures with respect to the spread of sunlight. If time allows, you may want them to break into small groups to interpret the figures briefly before discussing them as a full class. At the equinoxes, where is insolation most intense? (At the equator.) What about the solstices? It may be difficult to interpret exactly from the visualizations, but the greatest intensity is experienced at 23.5˚ N (the Tropic of Cancer) during the June solstice, and 23.5˚ S (the Tropic of Capricorn) during the December solstice. Students should be able to relate this to the pictures of Earth's tilt: during the solstices, sunlight reaches the Earth at a perpendicular angle not at the equator, but at one of the Tropics.

An alternative way to conduct this demonstration is included in the *Further Investigations* section.

Step 3. Introduce the Student Activity.

For this step, you will need a pre-assembled paper icosahedron (20-sided polyhedron) to serve as a model of Earth, from Figure EA-S4-4. See step 4 of this activity for assembly instructions. In the small group activity, student groups will assemble their own icosahedron of Earth, and use it to calculate the relative intensity of sunlight at different hypothetical degrees of Earth tilt, as you will now demonstrate.

You will also need a student protractor (Figure EA-S4-5) hanging on the wall, a sunlight circle (Figure EA-S4-6), and a copy of Table EA-S4-1 copied onto an overhead transparency so that the class can fill it in together.

You already demonstrated and discussed the effect of Earth's tilt on insolation received at different latitudes at different times of the year, which in turn causes seasonal change. In this exercise, students will quantify that effect, calculating relative sunlight intensity in the two hemispheres four times per year for each of several scenarios: no tilt, actual tilt (23.5˚), and greater than actual tilt (45˚). You will look at the scenario of actual tilt together as a class; students will then complete the other two scenarios in their groups and predict how seasons on Earth would be different if the Earth tilted more or less than it actually does.

Model the student activity as follows (students can follow along with the step-by-step instructions in their *Work Sheets*):

1. Explain that the *sunlight circle* in Figure EA-S4-6 represents the intensity of light from the sun as it spreads across a sphere (the globe). Like the grid you used earlier on the overhead projector, the sunlight circle is divided into sectors that each represent the same amount of solar energy. The sunlight circle is a flat representation of what happened to the squares on the grid when they were projected onto the globe. Near the poles, the energy spreads over a larger area: hence the elongation of the outermost sectors on the sunlight circle.
2. Position the icosahedron to show the correct tilt of the Earth using the protractor you have hung on the wall. Line up the model Earth's poles with the 0° mark on the protractor; the equator should be horizontal. Now rotate the Earth clockwise by 23.5˚, as measured by the protractor.
3. Begin by modeling the June solstice. Position the sun (represented by the sunlight circle) at its appropriate orientation to the tilted Earth (see Figure EA-S4-7, step A and B). Hold the sunlight circle perpendicular to the protractor and to the right of the icosahedron. Move the sunlight circle toward the model Earth until it touches at one point.
4. It is helpful to ask students to think about what the sunlight circle represents. Think of the sunlight circle as a cross-section of the light coming to Earth from the sun. Figure EA-S4-7a, Step C shows how the light represented by the circle would project onto the spherical Earth. During the June solstice, you can see that more of the light falls in the Northern Hemisphere, and no light falls on the South Pole at all.

Earth-Sun Relationships

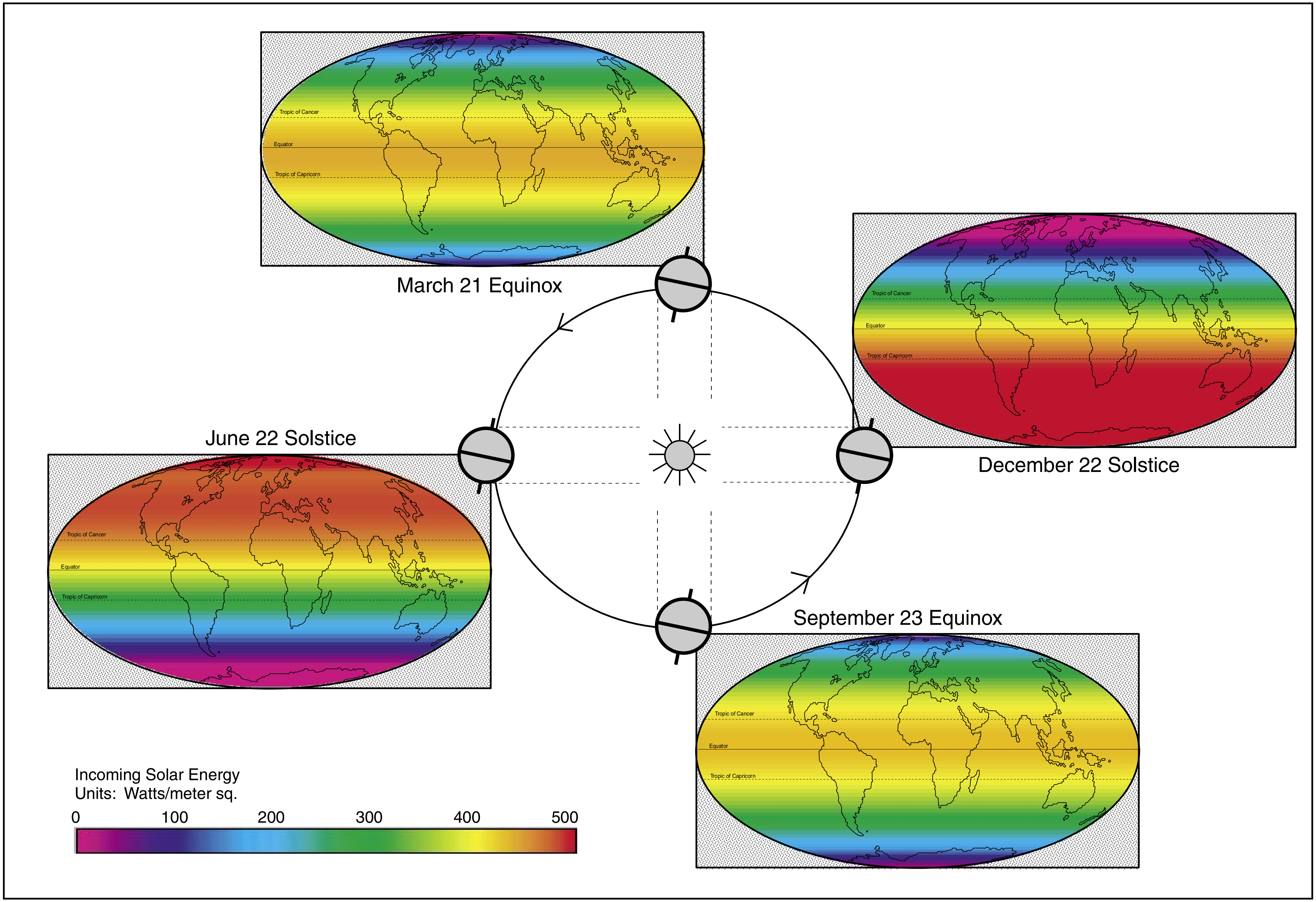


Figure EA-S4-2: Earth-Sun Relationships: Phy

Figure EA-S4-3: Grid to use for Step 3 demonstration showing the spread of sunlight over a sphere

Grid

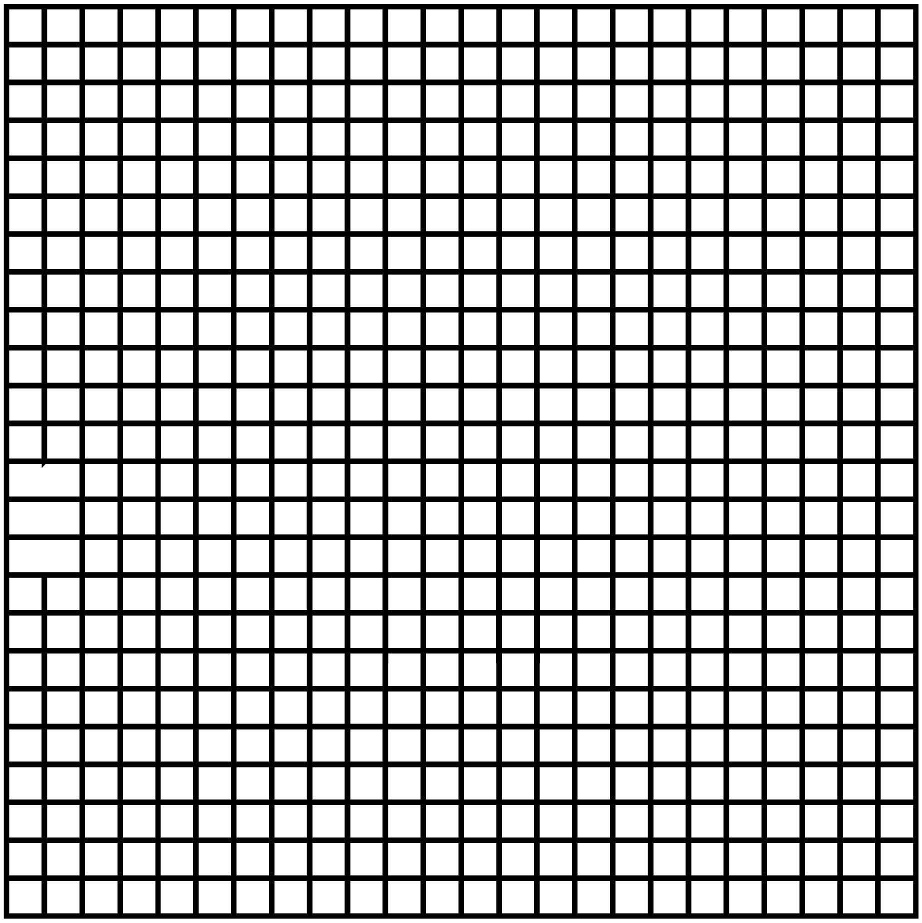
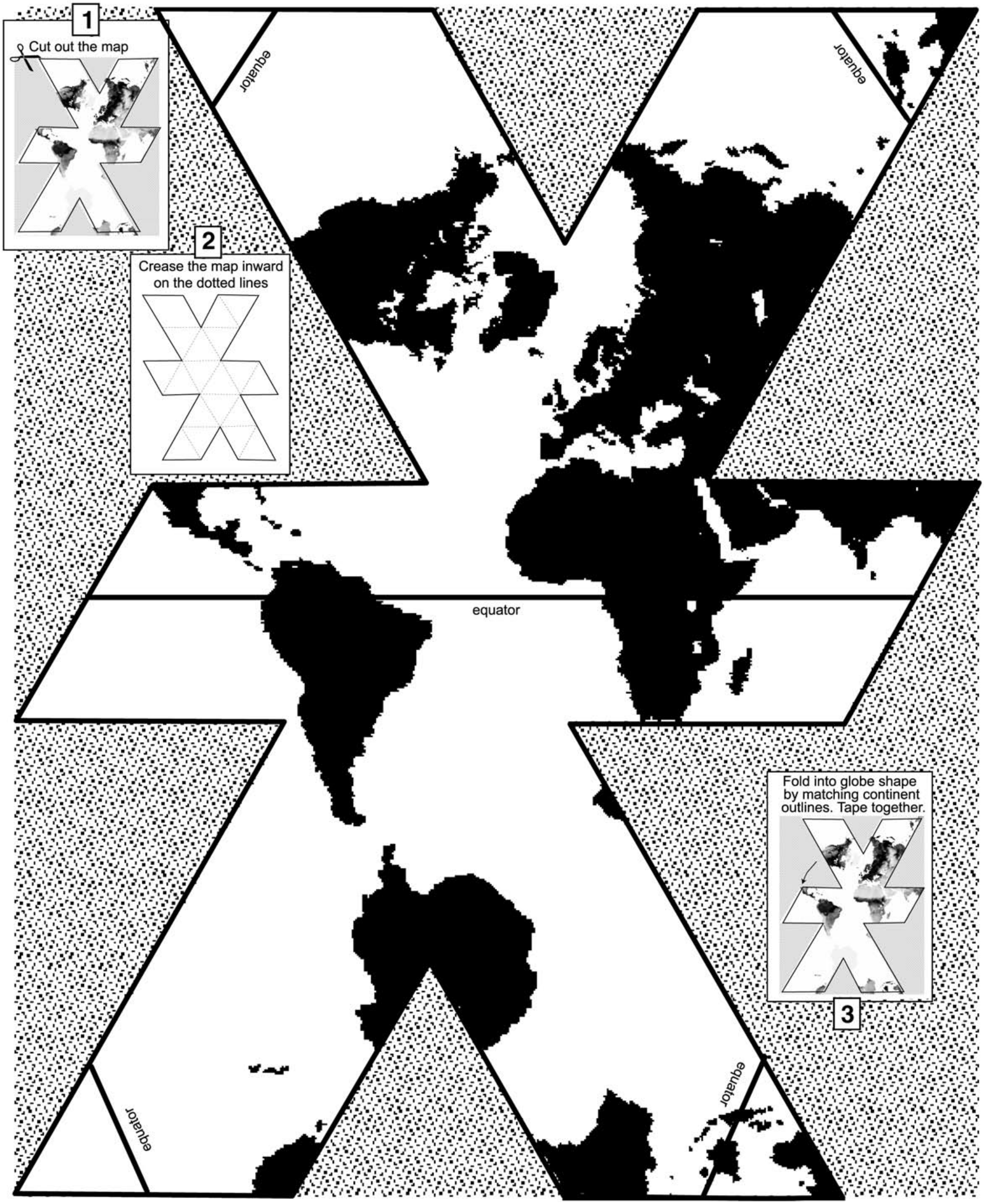


Figure EA-S4-4



5. To compare the relative insolation received in the two hemispheres, you will need to know where the equator intersects the sunlight circle. Roll the Earth against the sunlight circle until the equator touches it (Figure EA-S4-7a, Step D), and ask a student to make a pencil mark on the circle where the equator intersects it (it should be on or near one of the darker lines pre-marked on the sunlight circle). Using Figure EA-S4-7b, Step E, as a guide, pencil in a curved line symbolizing the equator on the sunlight circle.
6. Count the energy sectors on the circle that fall above and below the penciled-in equator line. There are 80 total sectors, so the sum of sectors above and below the equator line shall equal 80. For energy sectors that are bisected by the equator line, count the energy unit "in" the hemisphere that over half of the sector falls in (Figure EA-S4-7b, Step F). Fill in the values in Table EA-SR-1 for the line labeled June solstice.
7. Repeat the calculation for the September equinox, December solstice, and March equinox. For each time of year, the tilt of the Earth stays the same – 23.5˚ clockwise on the student protractor – but the sunlight circle is in a different position: behind the Earth for the September equinox, to the left for the December solstice, and directly in front for the March equinox. To help figure out the correct orientation, you might ask students to think back to the demonstration in which you "orbited" around them with the globe: at each time of year, where was the sun with respect to the Earth?
8. What does Table EA-S4-1 tell us? Connect the values in the table back to the visualizations in Figure EA-S4-2, and to what students learned earlier. They may begin to notice patterns: for example, the insolation intensity at the equinoxes is the same in both hemispheres, and at the solstices the two hemispheres are opposite each other.

Step 4. Student Teams Each Assemble an Icosahedron.

Divide students into teams of 2-3, and give each team scissors, tape, a copy of the Work Sheet, and a copy of the icosahedron. The copy of the icosahedron shows the continents and 3-step instructions for folding. Assembling the icosahedron is useful for building visualization skills, as it demonstrates how a flat projection can become a three-dimensional object.

Guide students through the following steps:

1. Cut along the lines on the front of the icosahedron.
2. Fold in along the dashed lines shown in the folding instructions. The printed continent shapes should be on the outside. Each fold makes an equilateral triangle.
3. Tape the shape together.
    - Start in the center and work outward, putting tape on the inside of the figure until the last few edges.
    - Match the edges without overlapping; use the equator line and continent outlines as a guide to fit it together like a puzzle.
4. Before taping the last side, insert a pencil into the icosahedron and gently push against any flattened sides to round the shape out.
5. Tape the last side from the outside.

Step 5. Group Problem-Solving

Following the instructions on the Work Sheet, students can now complete Tables EA-S4-2 and EA-S4-3 to model relative insolation with a 0˚ tilt and 45˚ tilt. Before they begin, elicit their predictions about what they will find. Which tilt will cause a colder winter in the Southern Hemisphere? In the Northern Hemisphere?

Note that the instructions in the student Work Sheet ask them to begin by modeling a 23.5˚ tilt and filling in Table EA-S4-1, in case you chose not to model this scenario as a class. If you already completed Table EA-S4-1 together, instruct them to continue with Tables EA-S4-2 and EA-S4-3 in their groups.

As students conduct the activity, they may need help to figure out the correct orientation of the Earth to show different tilts, and the correct orientation of the sunlight circle at particular times of the year. The Earth should always be rotated *clockwise* by the appropriate angle for the scenario. As you work with each group, help them to think about the implications of the numbers they are writing down: how do the seasonal variations in the different scenarios compare?

The final step in the Work Sheet asks students to graph their results for all three scenarios, and predict what impacts the differences would have on climate and land cover at the poles and near the equator.

Step 6. Group Presentations and Analysis

Have each group present their ideas on how the climate, land cover, and animal adaptations would be different at 0˚ and 45˚ tilts. As students present their answers, encourage them to support their ideas with evidence from the graph and from what they already know about climate and habitats. As the students are describing their ideas, encourage them to use the three-dimensional model and the visualizations in Figure EA-S4-4. How would the colors change in the different scenarios?

Further Investigations

The GLOBE Web site allows a table (or spreadsheet) of visualizations to be created permitting a variety of visualizations to be contrasted, for example, in order to look at solar energy at different times of the year. Students can use this feature to conduct further investigations, for example, into how insolation varies over time. The GLOBE *Earth Systems Poster* provides an excellent table that allows insolation visualizations to be compared and contrasted with visualizations of other variables such as temperature and vegetation vigor.

This activity explains two primary causes of seasonal change, explaining why seasons are experienced differently at different latitudes. The *Seasonal Change on Land and Water* Learning Activity explores the effects of large landmasses on the local experience of seasonal change.

Step 3 of this activity offers a mechanism for demonstrating the way that sunlight hits the Earth because of its spherical shape. An alternative demonstration is presented here:

- Copy the grid in Figure EA-S4-3 onto an overhead transparency, and use an overhead projector to project it onto a flat sheet of paper taped to the wall. This represents how the sun's energy would hit the Earth *if* the Earth were a flat two-dimensional plane, like the paper.
- Ask a student to trace the projected grid on the paper with a pencil or marker.
- Next, wrap another piece of paper around a globe, ball, or other spherical object, making sure that the paper wraps at least halfway around. Now project the grid onto the globe and have a student trace the grid onto the paper wrapper. Also on this paper, indicate where the equator and poles lie.
- Unwrap the paper from the globe and compare the two tracings. What is different and why? How does the size of the projected grid–with each segment representing areas that receive equal amounts of energy–relate to seasonal change?
- Now, tilt the Earth by approximately 23.5˚ so that one pole is tilted toward the "sun" (the projector) and the other pole is tilted away. What happens to the grid sizes in the two hemispheres? What does that imply for Earth's temperature patterns?

Figure EA-S4-5: To Model Tilt of the Earth in Different Scenarios

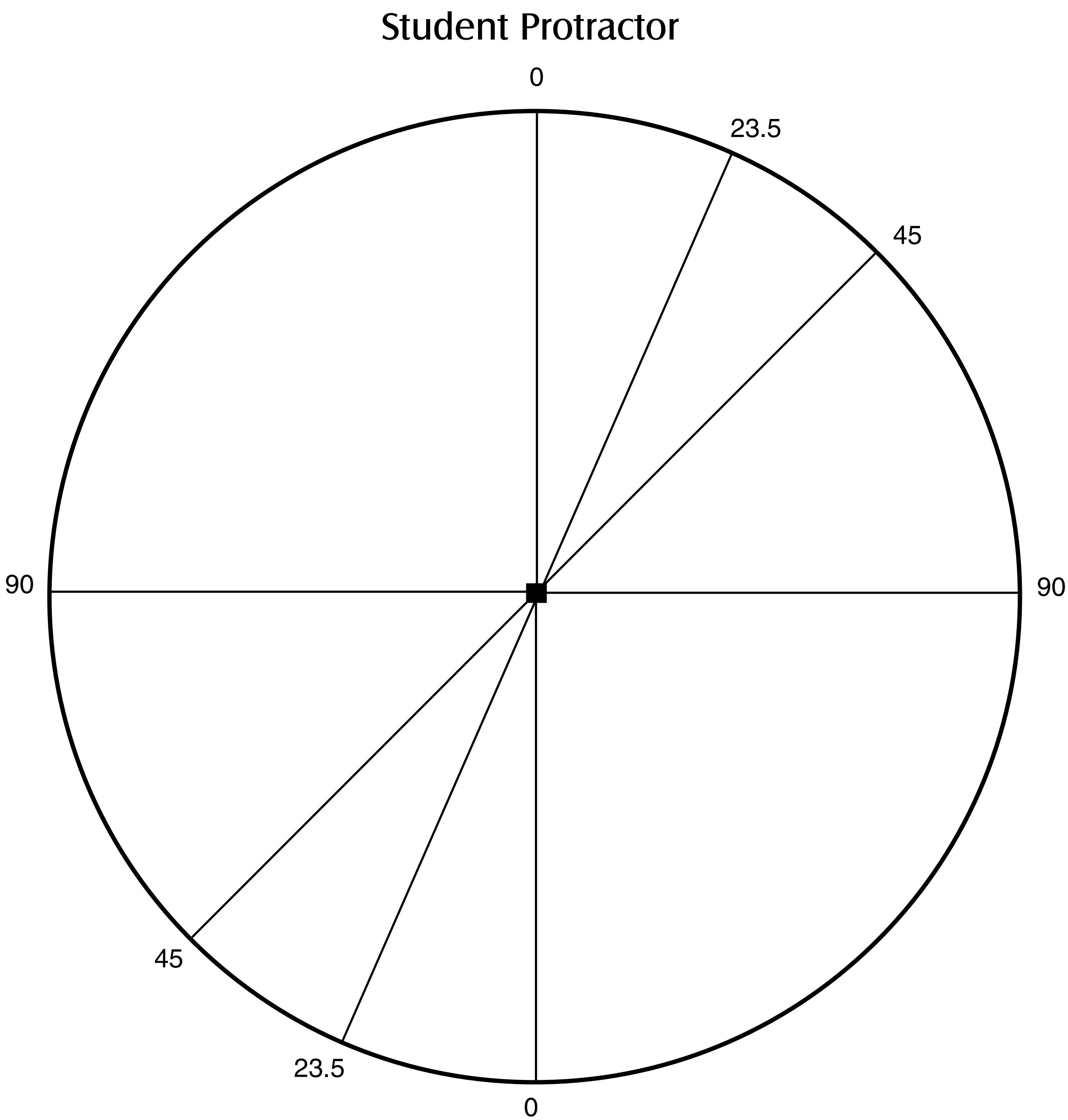
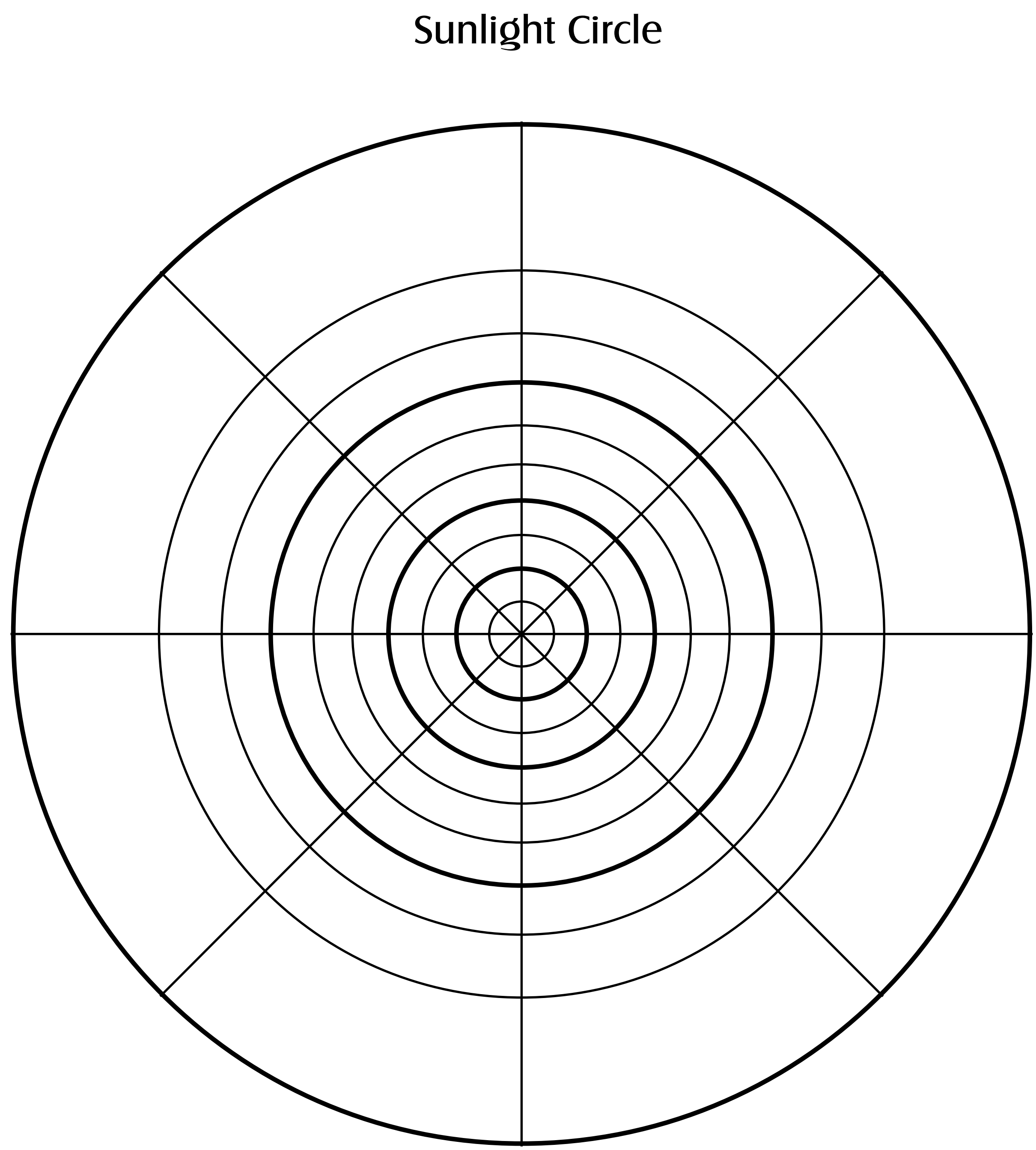


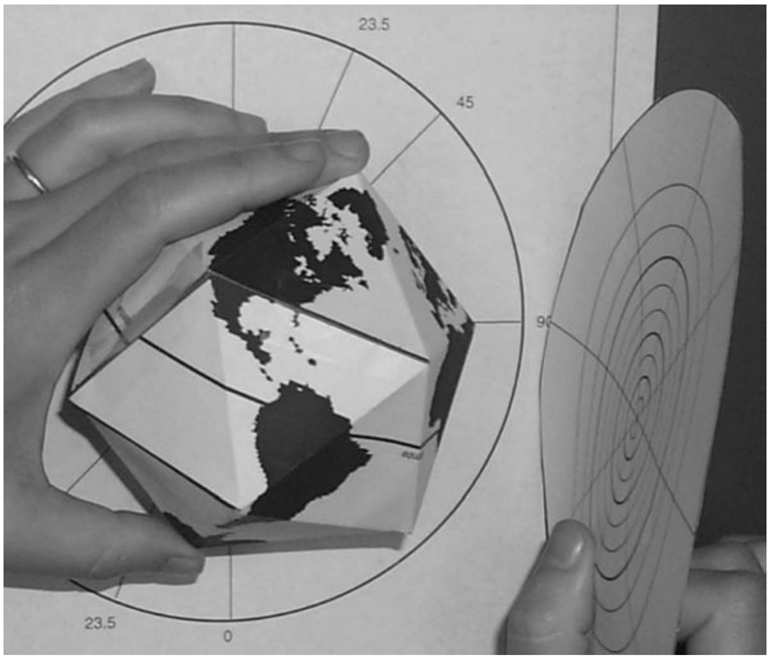
Figure EA-S4-6: The Sunlight Circle represents the distribution of sunlight over the spherical Earth.



Note: The sunlight circle shows how sunlight spreads over the sphere of the Earth. Each section of the sunlight circle represents an equivalent amount of solar energy. Solar energy is greatest at the point on the Earth where sunlight is coming in at a 90° angle (represented by the small sectors). As the angle of incoming sunlight changes, the intensity decreases, because the same amount of energy is spread over a greater area on the sphere (represented by large sectors).

Figure EA-S4-7a

How to Use the Icosahedron and Sunlight Circle

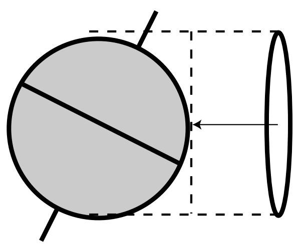


Step A/B

Orient Globe.

Hold the globe with the North Pole at 0° on the protractor.

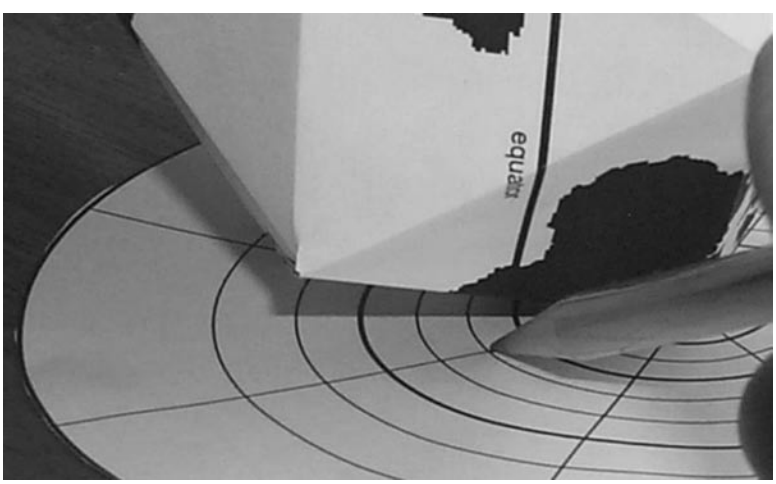
Rotate the globe clockwise to the desired tilt angle.

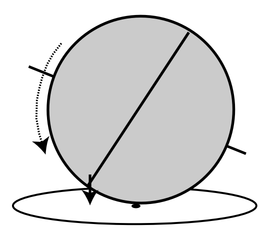


Step C

Orient sunlight circle.

Hold the sunlight circle perpendicular to the protractor to model an equinox.



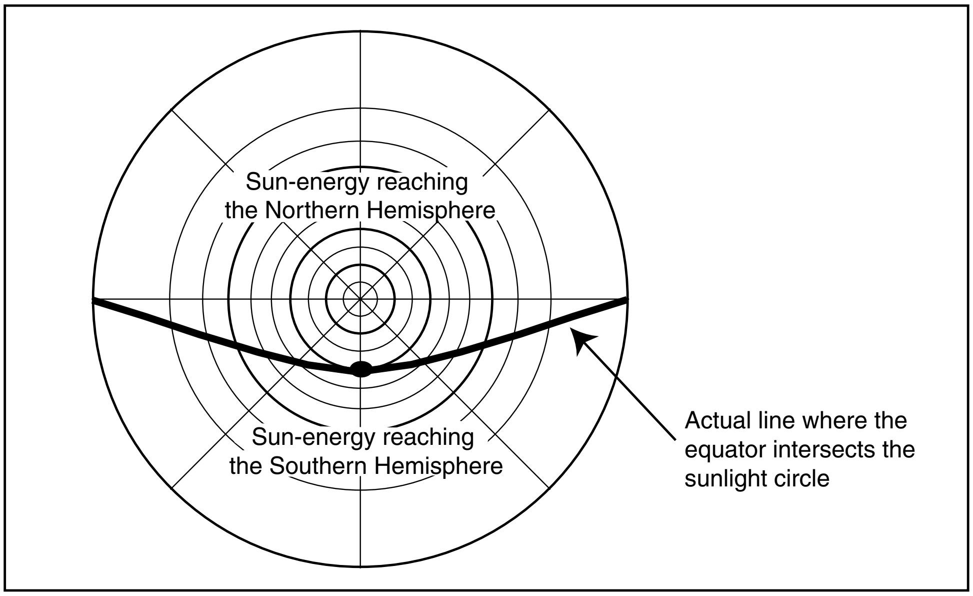


Step D

Mark the intersection of the equator with the circle.

Roll the globe until the equator touches the sunlight circle. Mark the point on the circle where the equator touches.

Figure EA-S4-7b: How to Use the Icosahedron and Sunlight Circle

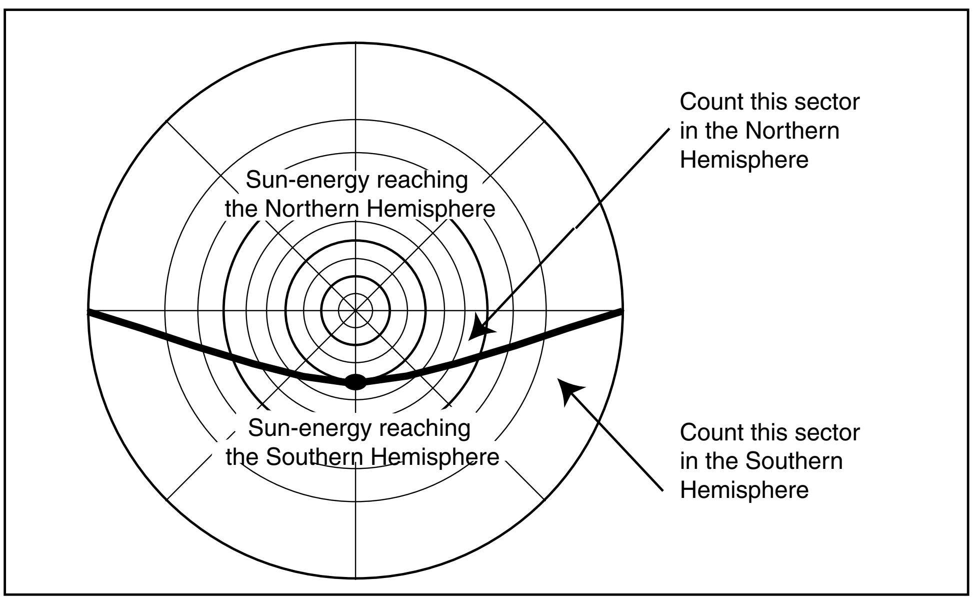


Step E

Mark the whole equator.

Draw a curved line connecting your pencil mark to the edges of the circle.

This line marks where the whole equator would intersect the sunlight circle.



Step F

Estimate energy sectors.

To estimate the number of energy sectors that fall into each hemisphere, count whole sectors. Where the equator line divides a sector, estimate which hemisphere contains most of the sector, and count it in that

Modeling the Reasons for Seasonal Change

Student Work Sheet

Names: ____

How does the Earth's tilt cause seasonal change? This Work Sheet will help you model how the tilt of the Earth causes changes in the amount of solar energy received by each hemisphere as the Earth orbits around the sun. You will compare what happens now to what would happen if the Earth didn't tilt at all, or if it tilted more than it does now, and speculate on how our global climate would be different in these scenarios.

Directions

1. Cut out and assemble your model of Earth. You will be building a 20-sided polyhedron called an icosahedron *(iko-sa-hee-dron)*. The directions for assembling it are on the icosahedron page itself.

2. Experiment with the concept of tilt using the paper Earth you just constructed. One student on your team stands in one place to represent the sun. Another student holds the paper Earth at a clockwise tilt and then, *without changing the orientation of the paper Earth,* walks around the sun to represent the Earth's orbit, *facing in the same direction the whole time*. Take a look at Figure 1 to see how the Earth would be oriented with respect to the sun at the March equinox, June solstice, September equinox, and December solstice; pause in your "orbit" at those points. At what time of year does the sun get a clear view of both poles?

   ____

   Of one pole but not the other?

   ____

3. Cut out the sunlight circle (Figure EA-S4-6) which is marked off into 80 segments. The sunlight circle shows how sunlight spreads over the sphere of the Earth. Each sector of the circle represents the same amount of solar energy. Solar energy is greatest at the places on Earth where sunlight is coming in at a perpendicular (90˚) angle. As the angle of incoming sunlight changes, the intensity decreases because the same amount of energy is being spread over a greater area, as shown by the elongated shapes at the edges of the sunlight circle.

4. You will be using your icosahedron and sunlight circle, and doing some calculations in Tables 1, 2, and 3, to see how sunlight spreads over the two hemispheres at the Earth's actual tilt (23.5˚; Table EA-S4-1) and compare that to what would happen if the Earth didn't tilt at all (0˚ tilt, Table EA-S4-2) or if it tilted more than it actually does (45˚ tilt, Table EA-S4-3). Follow the steps below to see how solar energy received in the two hemispheres compares at particular times of the year at a 23.5˚ tilt; you will repeat these steps for the other two scenarios.

   Step A: First, use your protractor to line up your Earth model at the right tilt (for Table EA-S4-1, this is 23.5˚). Tape your protractor onto the wall or have someone hold it parallel to the wall, with the 0˚ mark pointing up. Start with the North Pole lined up with 0˚. Then rotate the Earth model clockwise to 23.5˚. The picture in Figure EA-S4-7A, Step A/B, can help you see how to do this.

Step B: Now position the sun, represented by the sunlight circle, at its appropriate orientation to the tilted Earth. You will be doing this four times, for the two equinoxes and the two solstices. Begin with the June solstice. As shown in Figure EA-S4-7A, Step A/B, hold the sunlight circle perpendicular to the protractor and to the right of the icosahedron. Look at Figure EA-S4-1 to see why this is the correct orientation: the North Pole is tilted toward the sun.

Step C: Move the sunlight circle toward the model Earth, so that it touches at one point in the middle of the sunlight circle. This point is where the sunlight will be hitting the Earth at a 90˚ angle, which means the sun's energy is most intense at this latitude. Table EA-S4-1 lists the latitudes of perpendicular rays at four points during the year. Did your model intersect at about the right place for the June solstice? Given the Earth's tilt, why does this latitude make sense?

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Predict the latitudes of perpendicular rays for a 0˚ tilt and a 45˚ tilt, and fill in these values in Tables EA-S4-2 and EA-S4-3.

Step D: Now, calculate the amount of energy received in each of the two hemispheres by tracing the position of the equator on the sunlight circle. Without changing the orientation of the Earth, roll it against the sunlight circle until the equator touches the circle, and mark that point on the sunlight circle with a pencil (as shown in Figure EA-S4-7A, step D).

Step E: Draw a curved line from the point you marked on the sunlight circle to the horizontal equator on the sunlight circle (see Figure EA-S4-7A, Step E). This is the intersection of the Earth's equator with solar energy as it is projected onto the sphere of the Earth. In the sunlight circle, each segment represents one unit of solar energy. The segments *above* the line you drew represent the solar energy reaching the Northern Hemisphere, and the segments *below* the line represent the solar energy reaching the Southern Hemisphere.

Step F: Count the number of sectors that fall into each hemisphere, and enter that information into Table EA-S4-1. Figure EA-S4-7a, Step F shows how to count the sectors. If the line passes through a sector, count that sector in the hemisphere it falls mostly into. The total number of sectors you count should add to 80.

Step G: Now repeat Steps A-F for the other times of the year: the September equinox, the December solstice, and the March equinox. Each time, the orientation of the Earth stays the same, but the relative position of the sunlight circle changes as the Earth orbits around the sun. To model an equinox, the sunlight circle should be parallel to the protractor, either in front of the globe or behind it so that, from the perspective of the sun, the Earth is tilted to the left (September) or the right (March). For the December solstice, the sunlight circle should be to the left of the Earth so that the South Pole tilts toward the sun.

Step H: In Table EA-S4-1, calculate relative amounts of sunlight in each hemisphere at the four different times of the year. At what time of year does the Northern Hemisphere receive the greatest amount of solar energy? The least?

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5. Now repeat Steps A-H to see how the spread of sunlight over the two hemispheres would change if the Earth did not tilt at all (Table EA-S4-2) or if it tilted by 45˚ (Table EA-S4-3). Each time, all the steps are the same except for the first one, where you rotate the model Earth to the appropriate tilt for the table you're working on. You may want to mark the sunlight circle with a different color for each scenario.
6. Finally, compare the three scenarios you just modeled by completing the graph "Comparing Sunlight Distribution as the Earth Tilts." First, decide which hemisphere you want to graph and circle it on the top of the graph. Next, select a symbol (circle, square, *, etc.) to represent values in each of the three tilt scenarios, and enter those in the legend. Finally, using the symbols you selected, graph the percentages you calculated in Tables EA-S4-1, EA-S4-2, and EA-S4-3 to show the change in incoming solar energy in this hemisphere over the course of a year. Draw lines to connect the values you graphed for each tilt scenario: 0˚, 23.5˚, and 45˚
7. Using what you learned in the modeling exercise and the graph you just drew, answer the following questions. Use evidence from the graph and the models to back up your claims.

a. How does the Earth's tilt affect the seasons? Be as specific as you can about the causes of seasonal change.

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b. How does the Earth's spherical shape change local experience of the seasons at high latitudes and at the equator?

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c. How would the seasons be different if the Earth tilted differently than it does? Think about the following observable differences:

How would temperatures where you live be different than they are today if the Earth didn't tilt at all? If it tilted more than it does today?

How might plants and animals adapt differently to their new climates if the Earth didn't tilt at all? If it tilted more than it does today?

How much larger or smaller would Earth's regions of permafrost (permanently frozen subsoil) be if the Earth didn't tilt at all? If it tilted more than it does today?

Table EA-S4-1: Actual Earth Tilt (23.5°)

Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox	0°				
June solstice	23.5°				
September equinox	0°				
December solstice	23.5°				

Table EA-S4-2: No Tilt (0°)

Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox					
June solstice					
September equinox					
December solstice					

Table EA-S4-3: Greater-Than-Actual Earth Tilt (45°)

Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox					
June solstice					
September equinox					
December solstice					

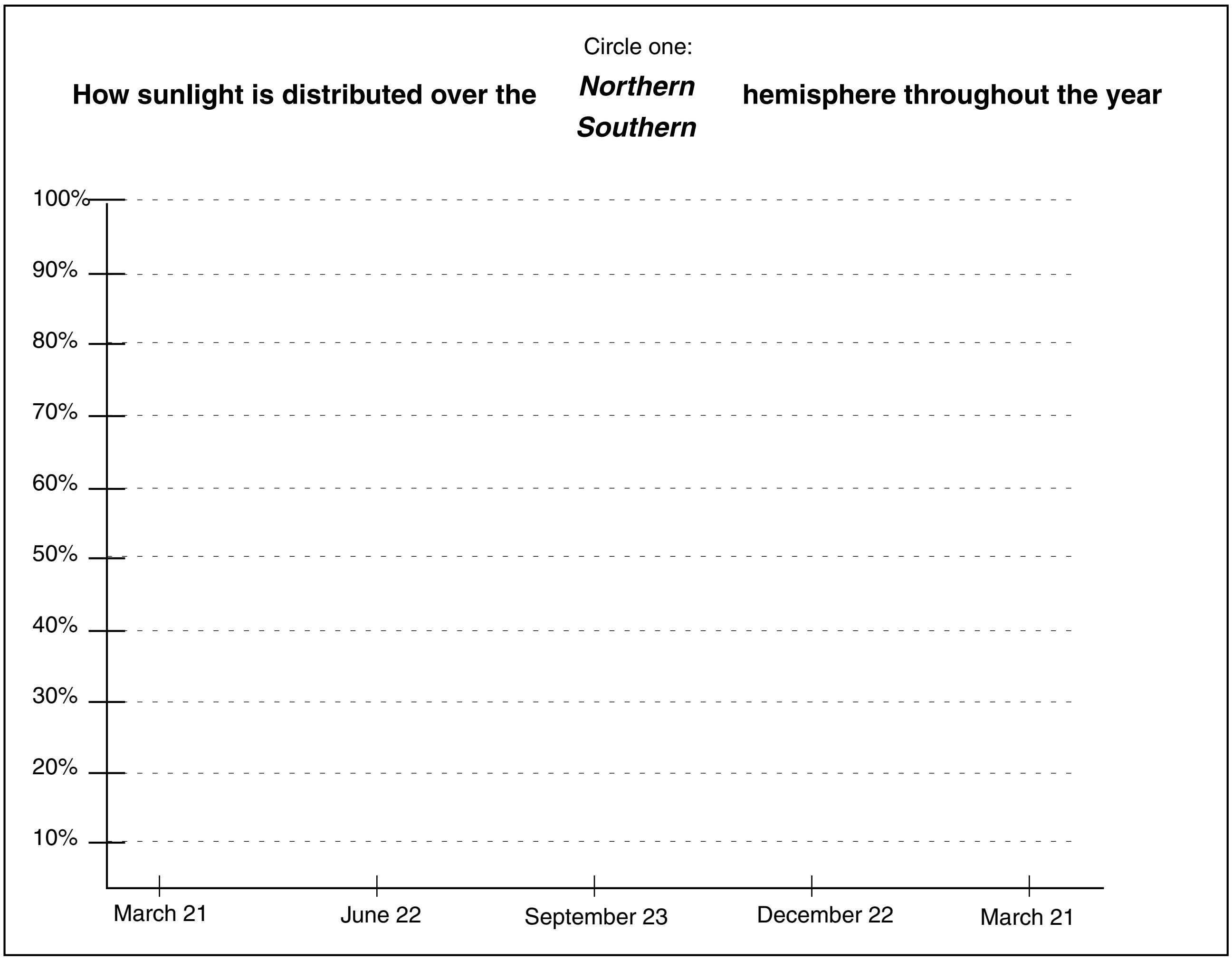
Comparing Sunlight Distribution As the Earth Tilts Work Sheet

Legend

0° tilt symbol

23.5° tilt symbol

45° tilt symbol



Comparing Sunlight Distribution: Graph the results of one hemisphere's data from Tables EA-S4-1, EA-S4-2, and EA-S2-3. to illustrate different distributions of sunlight in different Earth tilt scenarios.

Modeling the Reasons for Seasonal Change

Rubric

For each criterion, evaluate student work using the following score levels and standards.

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, but needs improvement

0 = Answer is blank, entirely arbitrary or inappropriate

1. Observe student groups modeling physical phenomena with the icosahedron, sunlight circle, and protractor (steps 1-3 and 4A-C).

Score Level	Description
3	Student groups have correctly assembled an icosahedron so that it resembles a sphere. The protractor is taped on the wall at the right orientation so that it can be used to tilt the paper Earth. The students can show the proper orientation of the paper sunlight circle with respect to the Earth at the two solstices and two equinoxes.
2	One of the following is observed: the icosahedron is assembled incorrectly making the modeling difficult, or the protractor and/or sunlight circle are not oriented correctly.
1	Student models are incorrect.
0	Students do not attempt to model the activity.

2. Observe student groups interpreting the modeling exercise above. Students explain their understanding of the physical model.

Score Level	Description
3	Students can explain how the alignment of the icosahedron with the sunlight circle correlates with the Earth's orbit around the sun. The students understand how the tilt affects the location where the suns rays are perpendicular to the Earth, and have recorded this correctly in Tables EA-S4-1, EA-S4-2, EA-S4-3.
2	One of the following is missing: students cannot explain how the sunlight circle correlates with Earth's orbit, or cannot explain how tilt affects the location of perpendicular rays. The wrong values are entered for perpendicular rays in Tables EA-S4-1, EA-S4-2, EA-S4-3.
1	Student interpretations are incorrect.
0	Students do not attempt to model the activity.

3. Observe student groups calculating numerical values from the icosahedron and sunlight circle for all tilts that are modeled (steps 4D-H and step 5).

Score Level	Description
3	Students have marked the sunlight circle with the point where it intersects the Earth and that point is close to the correct darkened line on the sunlight circle. When questioned, students show that they understand that the segments above the equator line represent sunlight hitting the Northern Hemisphere and those falling below represent sunlight hitting the Southern one. Students obtain the correct values for Tables EA-S4-1, EA-S4-2, EA-S4-3. (see values below). For 4H, students answer June solstice and December solstice.
2	Students have placed the line in the incorrect place on the sunlight circle, but have done the counting and percentage calculations correctly. Alternatively, they have placed the line in the correct place, but have done the calculations incorrectly. When questioned, students show that they understand that the segments above the equator line represent sunlight hitting the Northern Hemisphere and those falling below represent sunlight hitting the Southern one. For 4H, students answer June solstice and December solstice.
1	Students fill in the table incorrectly or cannot explain what the values mean.
0	Answer is blank, entirely arbitrary or inappropriate.

4. Students correctly graph the values from the table onto the graph (step 6).

Score Level	Description
3	Students have indicated which hemisphere they are graphing, have chosen symbols and filled in the legend. Data from all three tables are shown on the graph. Curves show correct overall pattern (see student example below) and use correct specific values.
2	Students have indicated which hemisphere they are graphing, have chosen symbols and filled in the legend. Data from all three tables are shown on the graph. Curves show correct overall pattern (see number 1 below) but are wrong as regards to their specific value.
1	Legend is missing. Curves are drawn but fail to show the right pattern. All curves should be at their highest during the summer, fall to a middle level during the equinox, fall to their lowest point during the winter, and then rise back to a middle point during the equinox. All curves should show the same value during the equinoxes. One possible reason for the curves being wrong is that students forgot to graph the percentages and instead have graphed the number of squares.
0	Answer is blank, entirely arbitrary or inappropriate.

5. Explain how the Earth's tilt affects seasons (step 7a).

Score Level	Description
3	Student answer includes a mention of sunlight spreading over a sphere, and the tilt altering the locations where the sunlight hits at an angle close to 90˚.
2	Student answer omits one of the two points from level 3.
1	Student logic is incorrect.
0	Answer is blank, entirely arbitrary or inappropriate.

6. Explain how the Earth's spherical shape changes the seasons at the high latitudes and the equator (step 7b).

Score Level	Description
3	Student answers that the high latitudes get less intense sunlight due to the way sunlight spreads over the spherical Earth. Student may refer to class demonstration with globe and grid. Student refers to angle of sunlight being perpendicular at the equator.
2	Student answers that the high latitudes get less sunlight (vs. less *intense* sunlight). Or, student omits mention of sunlight at the equator.
1	Student only answers for equator or high latitudes and does not mention spread of sunlight.
0	Answer is blank, entirely arbitrary or inappropriate.

7. Explain how the seasons would be different under different scenarios of tilt (step 7c).

Score Level	Description
3	Student answers for both no tilt and more tilt. Student's answers include the following: **No tilt**: temperatures more even between same latitudes in each hemisphere; vegetation differences around the tropical latitudes would disappear; and the regions of permafrost would be larger as the freezing and thawing of the upper soil layer would not occur. **More tilt:** temperature extremes would move away from the tropic latitudes toward 45˚ at the solstices; vegetation of the arctic and tundra varieties would spread toward the equator; the regions of permafrost would be smaller.
2	Student omits one or two points from score level 3, or answers them incorrectly.
1	Student does not discuss both no tilt or more tilt, or uses incorrect logic to answer.
0	Answer is blank, entirely arbitrary or inappropriate.

Table EA-S4-1: Actual Earth Tilt (23.5°)

Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox	0°	40	50%	40	50%
June solstice	23.5° N	60	75%	20	25%
September equinox	0°	40	50%	40	50%
December solstice	23.5° S	20	25%	60	75%

Table EA-S4-2: No Tilt (0°)

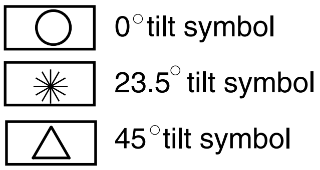
Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox	0°	40	50%	40	50%
June solstice	0°	40	50%	40	50%
September equinox	0°	40	50%	40	50%
December solstice	0°	40	50%	40	50%

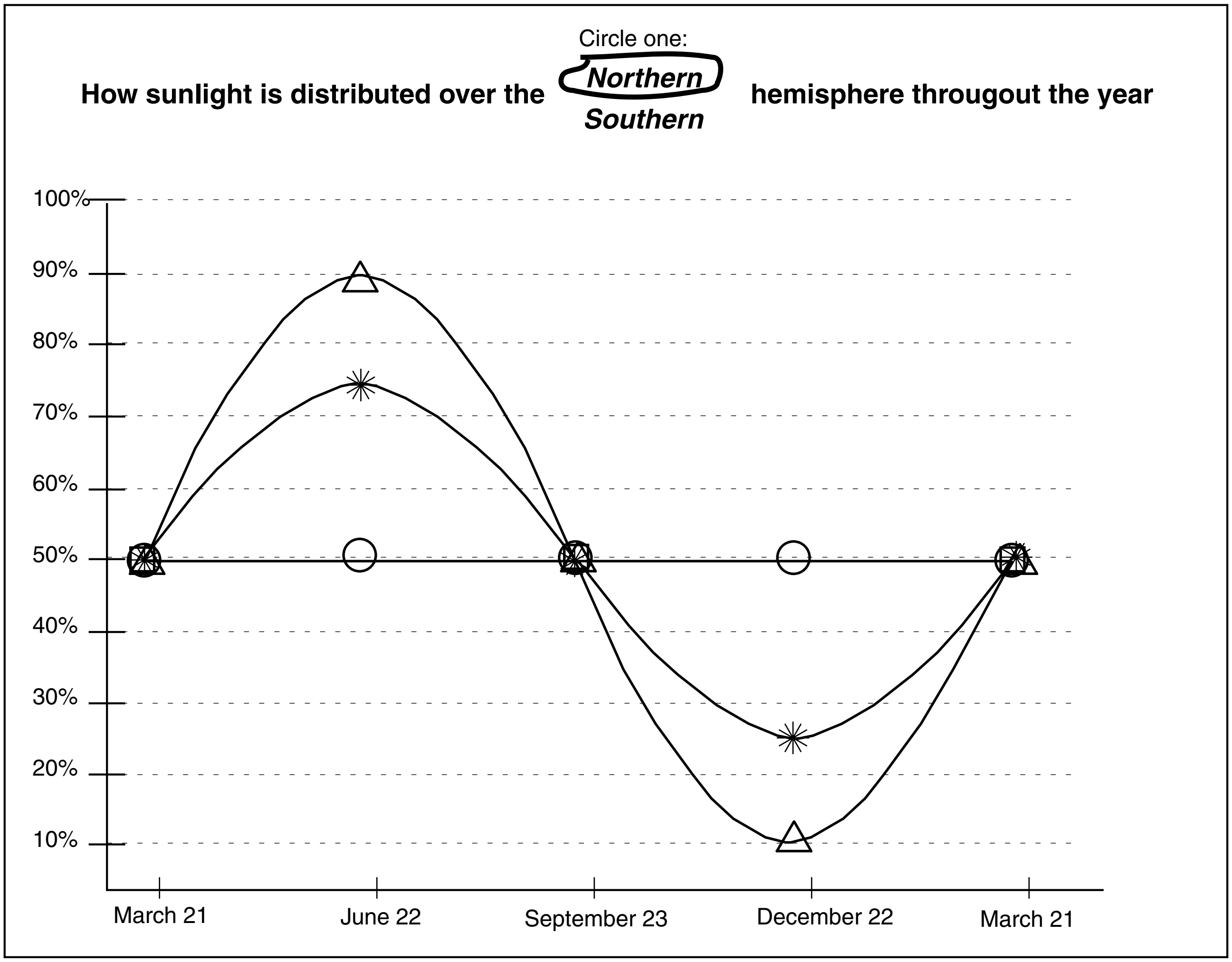
Table EA-S4-3: Greater-Than-Actual Earth Tilt (45°)

Total number of segments: 80		**Northern Hemisphere**		**Southern Hemisphere**	
Time of Year	Latitude of perpendicular rays	Number of sectors	% of total	Number of sectors	% of total
March equinox	0°	40	50%	40	50%
June solstice	45° N	72	90%	8	10%
September equinox	0°	40	50%	40	50%
December solstice	45° S	8	10%	72	90%

Comparing Sunlight Distribution As the Earth Tilts Work Sheet

Legend





S5: Seasonal Change on Land and Water

Purpose

To further students' understanding of the causes of seasonal change using visualizations to compare effects of incoming solar energy in the two hemispheres

Overview

The class reviews global visualizations of incoming sunlight and surface temperature and discusses seasonal change. Students use the visualizations to support inquiry on the differences in seasonal change in the Northern and Southern Hemispheres, culminating in an evidence-based argument about why one hemisphere experiences warmer summers although it receives less total solar energy.

Student Outcomes

Students can use color visualizations to understand phenomena and solve problems.

Students understand the link between heat capacity of land/water and climate variations between the two hemispheres.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation.

Sun is a major source of energy for phenomena on Earth's surface.

Physical Sciences

Heat energy is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Life Sciences

Sunlight is the major source of energy for ecosystems.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Analyzing visualizations for important patterns

Comparing and contrasting visualizations

Evidence-based argumentation

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Time

One 45-minute class period

Level

Middle, Secondary

Materials

Overhead transparencies of color visualizations and overhead projector

Copy of color visualizations for each student group. If high-quality color copies are not available, students can create them using *Work Sheet* copies and colored pencils or markers. Alternatively, if there are enough computers for each group (e.g., in a lab setup), students can access the visualizations on the GLOBE Web site.

Copy of *Work Sheet* for each student group

Wall map to support class discussions

Preparation

Create color copies of visualizations for each student group, or copy blank *Work Sheets* for students to color.

Divide students into groups of 2-3.

Prerequisites

Students should be familiar with the basic explanations for seasonal change: *Modeling the Reasons for Seasonal Change, Draw Your Own Visualization* and *Learning to Use Visualizations: An Example with Elevation and Temperature*.(suggested)

Background

Seasonal change can be partially explained by changes in insulation as the Earth orbits the sun and variations in the sun's intensity at different latitudes due to the Earth's tilt and its spherical shape. The GLOBE activity *Modeling the Reasons for Seasonal Change* explores these factors.

Taken alone, this explanation implies that seasonal change is the same throughout one latitude. Why, then, are Australia's coastal regions so much cooler than its interior, even at the same latitude? Incoming solar energy must not be the only factor in determining surface temperatures throughout the year. In this activity you will explore an additional factor: how land masses and bodies of water respond to the sun's energy.

Different materials respond to the energy from the sun in different ways. You have probably seen many examples of this. On a hot day, sand on the beach feels hot under your feet, but the water in the ocean feels much cooler. Similarly, it's usually cooler to walk barefoot in grass than on a nearby cement sidewalk. Scientists describe this phenomenon in terms of the amount of energy it takes to heat up different substances. *Heat capacity* is the ability of a material to absorb or lose energy before it changes temperature. Water has a relatively high heat capacity, requiring approximately 4.2 joules per gram of water to increase the temperature by 1˚ C. Conversely, one gram of water can lose 4.2 joules of energy before it cools by 1˚ C. In contrast, soil requires as little as 1.5 joules to heat up one gram by 1˚ C.

When land and water are exposed to the same amount of energy, land can heat up about three times faster than water. Conversely, land will cool down about three times as quickly as water. Actual heat capacity of soil varies depending on factors such as the water content of the soil: very moist soils have a higher heat capacity, closer to that of the water they contain, and therefore heat and cool more slowly than dry land. This is one reason that desert temperatures vary so greatly from daytime to nighttime.

Because of the difference in heat capacity between land and water, seasonal temperature patterns tend to be more extreme in large regions covered by land than in areas covered by water. Because water has a higher *thermal inertia*, than the ability to resist temperature change than land, large bodies of water tend to stay relatively constant in temperature throughout the year. This effect is relevant to global seasonal patterns because most of the land on Earth is in the Northern Hemisphere, thus making it easier to heat (or cool) than the Southern Hemisphere.

In this activity, you will use visualizations to explore the differences in received solar energy and resulting surface temperature between the Northern and Southern Hemispheres, and think about the implications for local climates.

What To Do and How To Do It

1. Conduct a class discussion to familiarize students with the visualizations.
2. Facilitate group work as students complete the *Work Sheets*.
3. Synthesize and discuss student findings as a whole class.

Step 1. Class Discussion

Seasonal Change: Review the spatial relationship between the sun and the Earth, and how Earth's tilt causes the amount of sunlight it receives in each hemisphere to vary, therefore causing the seasons. If students are unfamiliar with these issues, you can use the GLOBE activity *Modeling the Reasons for Seasonal Change* to teach them.

Ask: Are seasons exactly the opposite in the two hemispheres? For example, are January temperatures at latitude of 40˚ N the same as July temperatures at 40˚ S? If you wish, support this discussion by selecting a specific pair of locations at the same latitude in different hemispheres perhaps your town and a corresponding one in the other hemisphere and discussing their climates. Use GLOBE data or another Web site to make comparisons. This GLOBE learning activity will examine one of the reasons for the local variation of solar energy's effect on climate.

Orient Students to the Visualizations: Figures EA-S5-1 and EA-S5-2 present a set of visualizations showing incoming solar energy (Figure EA-S5-2) and surface temperature (Figure EA-S5-1) during two months (January and July). Each visualization shows a monthly mean, the average value for an entire month, at each location on the map. The months were chosen because they generally represent extremes of hot and cold in the annual surface temperature cycle. Consider beginning your explanation of these visualizations with surface temperature because it is a more familiar subject.

Surface Temperature

- In the surface temperature visualization (Figure EA-S5-1), colors have been selected so that there is a clear visual difference between the warm and cool temperatures. Colors that we refer to as "warm" (i.e., red, yellow, and orange) are used to represent warm temperatures. Colors that we refer to as "cool" (i.e., blue and purple) are used to represent cool temperatures. 3 C (32˚ F), the temperature at which water freezes, is where the transition from warm to cool or cool to warm occurs. This is an example of designing the colors for a visualization around a "landmark value." Landmark values are the points on a color scale where the representative value undergoes a distinctive change. Global patterns can be made easier to see by using landmark values that mark off the range at which certain phenomena occur. Designing a color scheme around a landmark value is useful in this case because it highlights which parts of the world are above or below freezing.
- Ask students to compare the two temperature visualizations, focusing on the areas that have below freezing temperatures. The visualizations show that in January both polar areas have sub-zero temperatures but that in July it is largely Antarctica that is below freezing. (Students will investigate this in the problem-solving activity.)
- Point out that the blues and greens on the map do not necessarily mean that the land at that location is frozen. The visualizations show average temperature over the whole month, including both daytime temperatures and nighttime temperatures, and in some areas pictured, temperatures are typically above freezing in the daytime and below freezing at night.
- Ask students to pick out different color patterns and connect them to their geographical causes: these patterns could be *minima*, *maxima*, or *contrast* with surroundings. For example, the Sahara Desert in Africa desert near the equator is the hottest place on Earth in July; the Rockies, Andes, and Himalayas are colder than their surroundings due to their high altitudes; and Greenland is shown as continuously frozen. This discussion may be aided by pointing out locations on a wall map of the Earth.

Solar Energy

- Solar energy comes to Earth in the form of sunlight and provides the Earth's primary source of heat. Solar energy is measured in units of watts per meter squared (watts/m^2). One way to make this more comprehensible is to relate it to light bulbs. For example, the average amount of energy coming to Earth in July is roughly 300 watts per meter squared. Students can imagine this as the energy from three 100-watt light bulbs for every square meter of the Earth. It is this energy that provides the basis for all life on Earth.

- The incoming solar energy visualizations in Figure EA-S5-2 show how energy is dispersed across the Earth. Why does the energy vary by latitude? The explanation for this has to do with how sunlight spreads over the spherical, tilted Earth. These spatial relationships are explored in another GLOBE visualization activity, *Modeling the Reasons for Seasonal Change*.
- The sun's energy is equal across lines of latitude (i.e., 40° N around the Earth on one day). Ask students to explain why this pattern occurs. They should refer to the Earth's daily rotation on its axis, which exposes each point on a line of latitude to the same amount of energy in a 24-hour period.
- Compare and contrast the two visualizations in Figure EA-S5-2. Ask students to describe the overall pattern of data in each visualization and to explain what the primary difference is between them.
- The pattern of incoming solar energy is very regular for each hemisphere. This leads to the following question: If solar energy is the primary cause of surface temperature, why do the surface temperature patterns vary from the solar energy patterns? One answer to this is that much of the energy from the sun is reflected away from the Earth-atmosphere system. For example, snow and ice can reflect up to 80% of sunlight. Clouds reflect strongly as well. This means that frozen surfaces can remain frozen despite substantial amounts of sunlight. In contrast, oceans and vegetation absorb most of the sunlight that falls on them and reflect little, thereby helping to warm the surface of the Earth. Other primary reasons are that surface temperature is strongly influenced by the type of material that is heated (such as land or water) and by air and water movements (i.e., air and ocean currents). This activity will investigate the impact of physical geography in some detail, focusing in particular on the effect of incoming solar energy on areas of land and water.

Step 2. Group Problem-Solving

The group problem-solving session asks students to further investigate the visualizations they discussed with the whole class, probing for why particular hemispheric patterns occur. The Work Sheet questions involve the students in considering fundamental climatic principles on Earth: the seasonal variation in the amount of sunlight (watts/m^2) received by different areas on Earth, the seasonal variation in temperature in the Northern and Southern Hemispheres, and the differences in how land and water respond to sunlight.

Students should work in groups of 2-3 for this exercise. The primary student materials are the color visualizations in Figures EA-S5-1, EA-S5-2, and EA-S5-3. It is easiest to conduct the analysis if each team has their own copy, either on paper or on computer (if this activity is done in a computer lab, each group could look at the visualizations posted on the GLOBE Web site). If neither of these is possible, copy and pass out *Work Sheets* 1-3 and color pencils or markers, so that students can create the color visualizations themselves by coloring in the template.

Guide students through the following steps.

A. *Students will use visualizations to compare incoming solar energy in January and July,* and see that the two hemispheres are almost opposite. They will also see that the Southern Hemisphere receives more energy during its summer than does the Northern Hemisphere. They are shown a depiction of the Earth's orbit around the sun as an aid to explain the difference: Earth is closer to the sun in January than in July. As students work, they may need help in interpreting the visualizations to support their inquiry.

B. *Students will compare temperature visualizations for January and July* to decide

Figure EA-S5-1

Average Earth Surface Temperatures for January and July

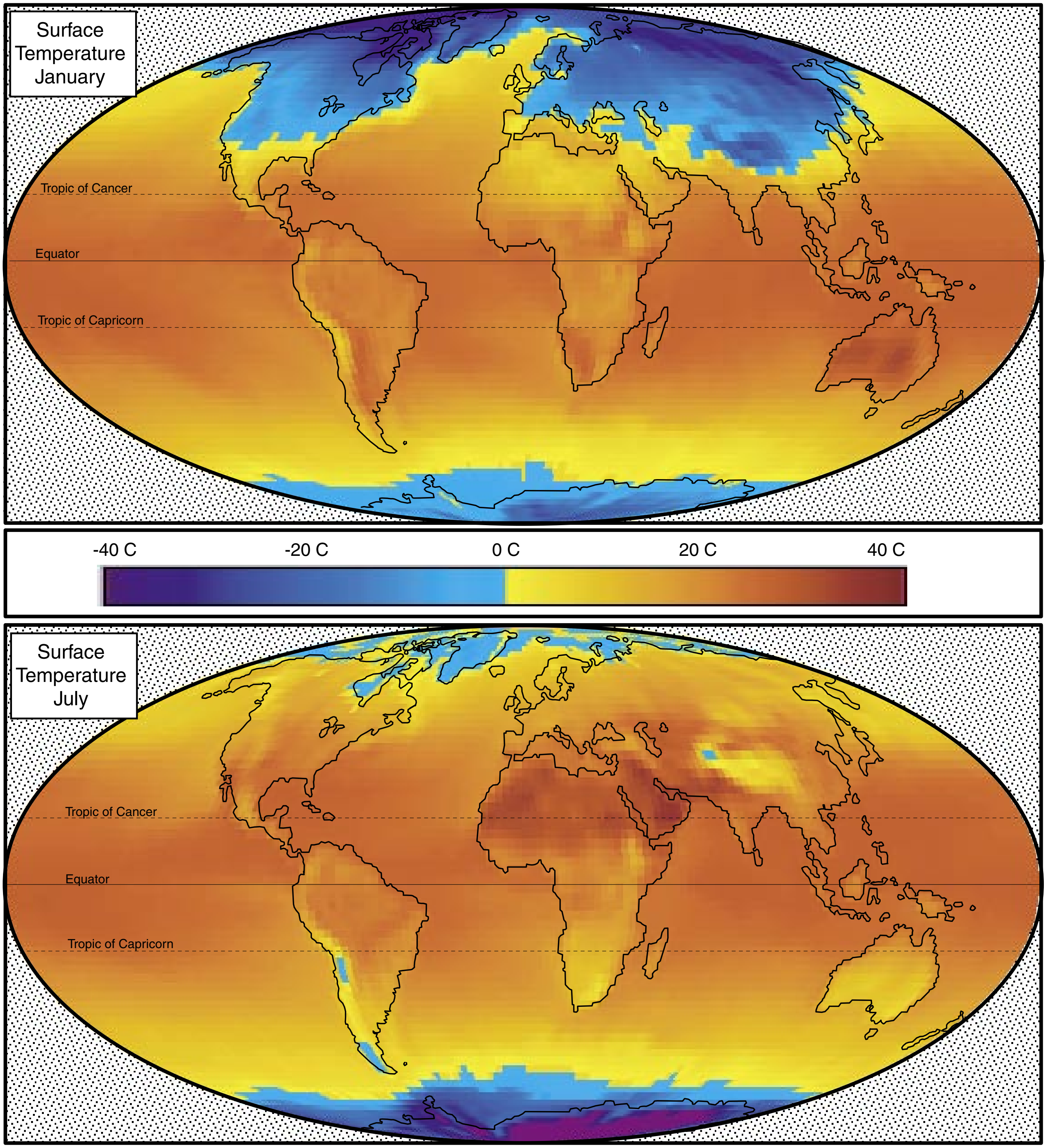
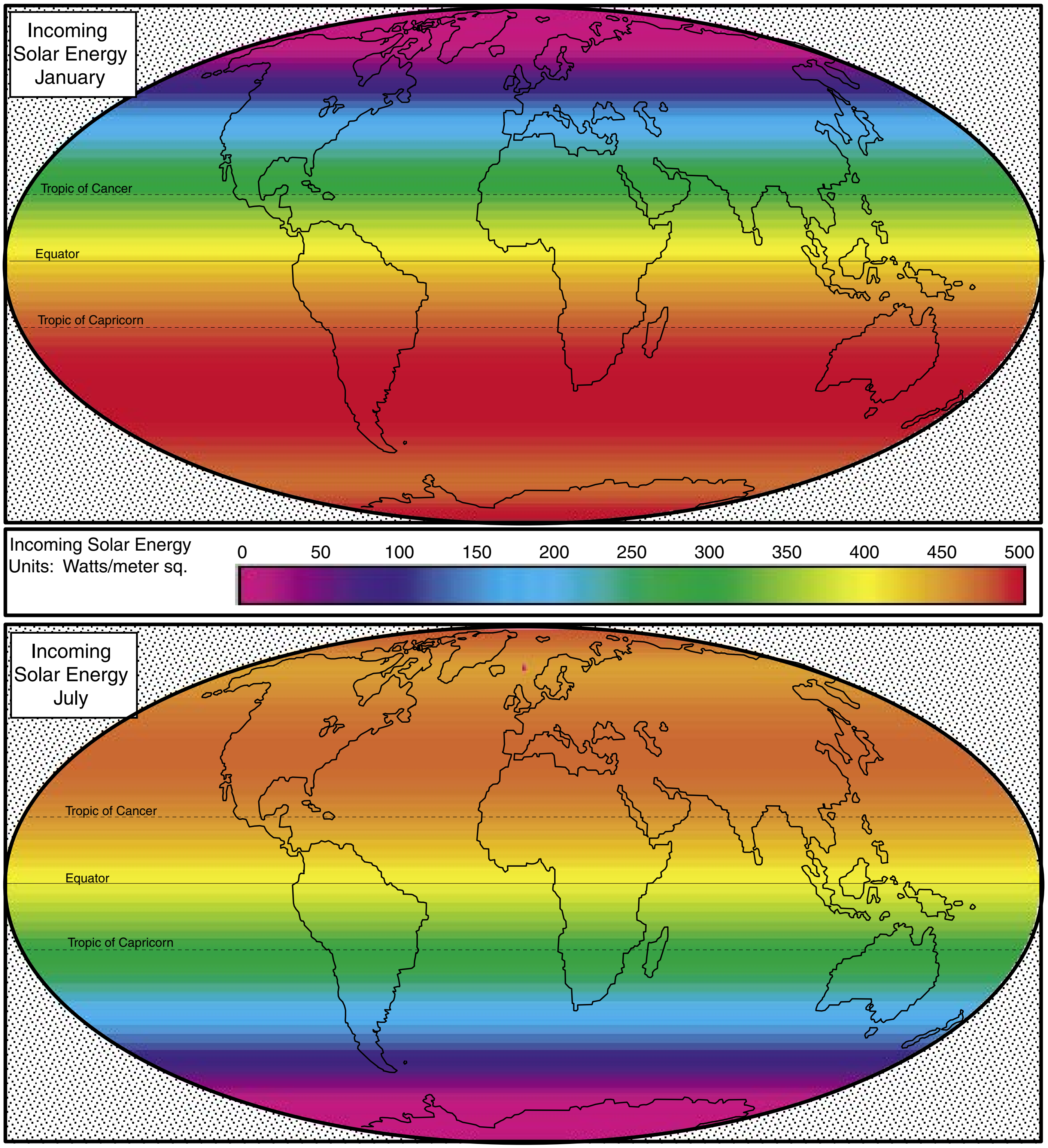


Figure EA-S5-2

Average Incoming Solar Energy for January and July



which hemisphere experiences a warmer summer. The temperature visualization shows that the Northern Hemisphere in July has more reds and dark reds than January in the Southern Hemisphere, and the graph of temperature averages shown in Figure EA-S5-3c shows this also. However, in July, the Northern Hemisphere received *less* insolation than the Southern Hemisphere did in January.

C. *Next, students will use Figure EA-S5-3a to compare temperature variation between two cities in opposite hemispheres: Beijing and Melbourne*. Figure EA-S5-3a shows a visualization of temperature range calculated as the absolute value of average temperatures for January minus average temperatures for July. Melbourne's temperature changes less even though the two cities are at similar latitudes. To explain this, students may look at GLOBE data for the two cities. Although altitude is an important factor in the difference, looking at fluctuations across the two hemispheres as a whole indicates that it is not a sufficient explanation. Australia is a relatively small landmass, while China is on a large landmass whose temperature will fluctuate significantly more than the nearby ocean.

D. *Students should generalize from this case to consider why surface temperature varies more in the Northern Hemisphere.* Figure EA-S5-3b shows a bar graph of the amounts of land and water in the two hemispheres to help students understand that the majority of land on Earth is located in the Northern Hemisphere, and as a result the Northern Hemisphere experiences more extreme temperature fluctuations than the Southern, which is covered mainly by water. Students should use specific evidence from the visualizations and graphics as support for their explanations.

Step 3. Class discussion

Have selected groups present their analysis. Guide them to support their explanations with evidence from the visualizations if they have not done so.

Many students believe that seasons are caused only by Earth's proximity to the sun and that summertime is warmer because the Earth is closer to the sun. This activity demonstrates that seasons vary despite proximity to the sun: summertime temperature change is in fact more pronounced when the Earth is farther from the sun and therefore receiving less intense incoming solar energy.

Further Investigations

An experiment that asks students to investigate the heat capacity of different substances would be useful to consolidate the underlying idea that some substances require more energy than others to raise their temperature. For example, a lab might ask students to expose a beaker of dirt and a beaker of water equally to a light source while they measure resulting changes in temperature. Similar issues can also be investigated through the GLOBE *Soil Moisture and Temperature Protocol.*

Another way to investigate heat capacity is to graph GLOBE data of air and water temperature. In general, the air temperature data will show more variation, consistent with the lower heat capacity of air relative to water. Comparing two schools at the same latitude where one school is near an ocean and another inland could continue this investigation.

Resources

The GLOBE Web Site offers a tool for creating a table (or spreadsheet) of visualizations, so that a variety of visualizations can be contrasted, for example, in order to look at incoming solar energy at different times of the year. Students can use this to conduct further inquiries, for example how solar energy varies over a year. The activity *Modeling the Reasons for Seasonal Change* uses visualizations as a means for analysis of contrasting solar energy during the solstices and equinoxes. The GLOBE Seasons Poster also provides a comprehensive table of this sort allowing solar energy visualizations to be compared and contrasted with visualizations of other variables including average temperature, cloud cover, precipitation, soil moisture, and vegetation vigor.

Figure EA-S5-3 a,b,c

Land Mass Distribution and Seasonal Temperature Change

Figure EA-S5-3a: Temperature Difference Between January and July

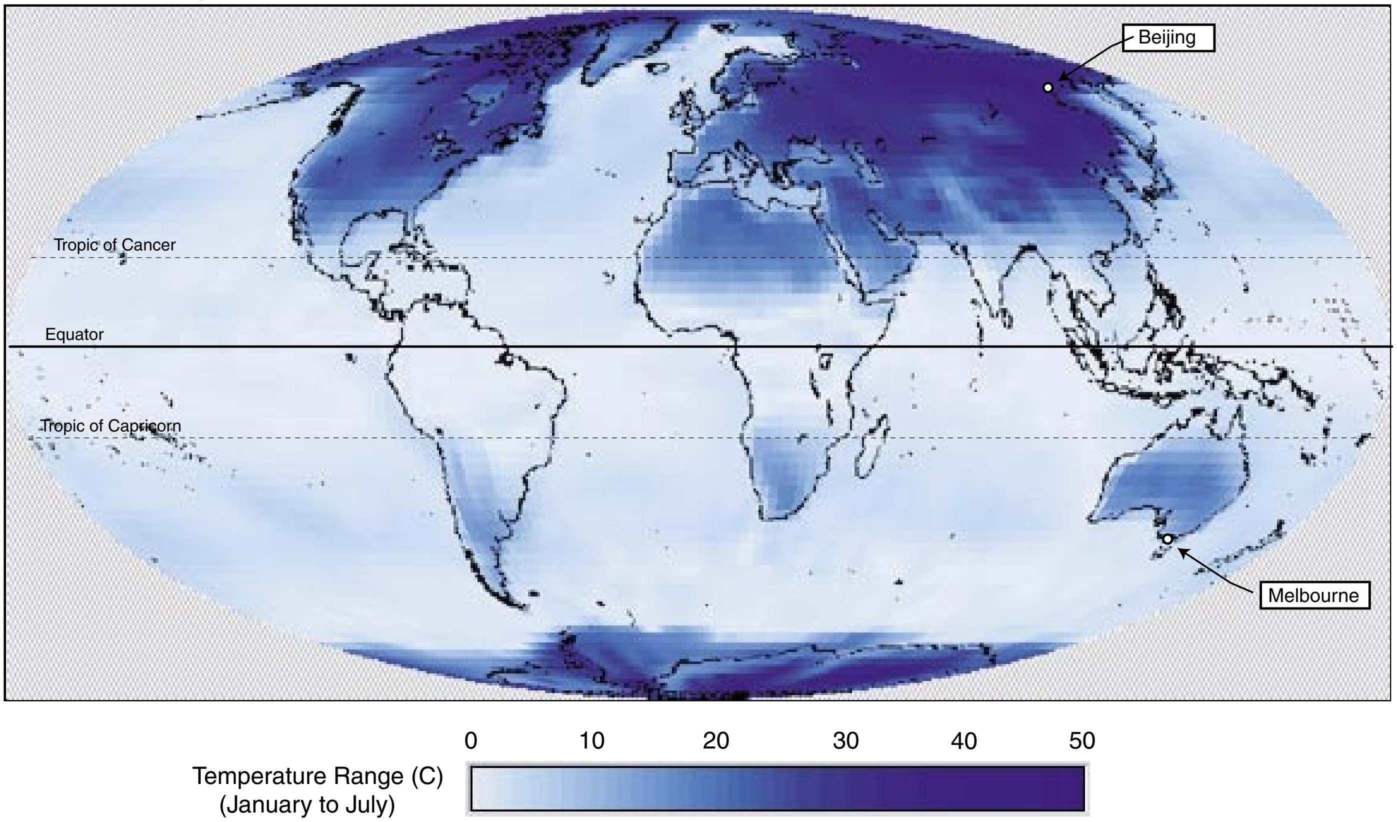


Figure EA-S5-3b: Area of Land and Water by Hemisphere

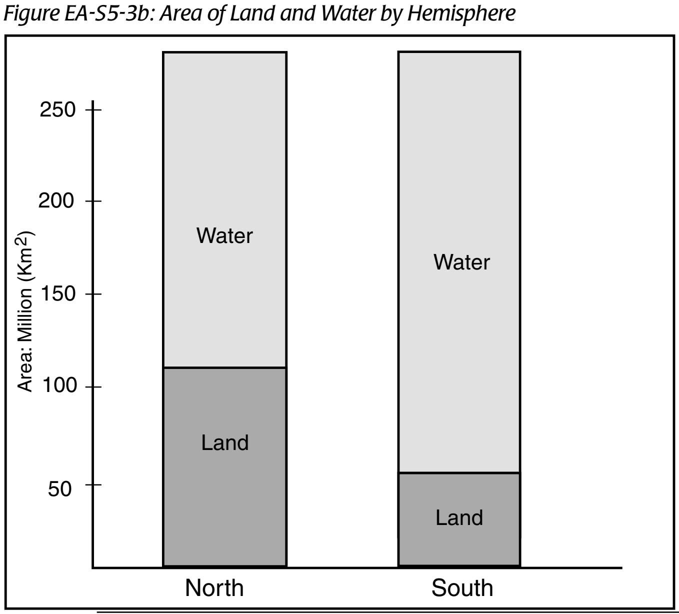
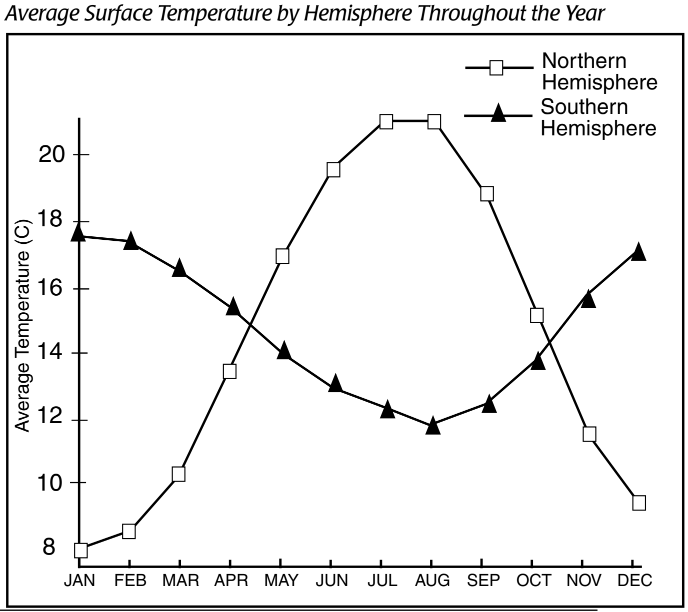


Figure EA-S5-3c:
Average Surface Temperature by Hemisphere Throughout the Year



Seasonal Change on Land and Water

Work Sheet

Names: ____

Seasons are more or less, but not exactly, opposite in the Northern and Southern Hemispheres . In this activity you will use color global visualizations and other data to analyze and explain important differences in the variation of seasonal change in the hemispheres.

Directions

1. Begin by looking at the visualizations of incoming solar energy for January and July (Figure EA-S5-1 or *Work Sheet 1*). Which hemisphere is experiencing its summer in January? (Northern/Southern) In July? (Northern/Southern) Explain how the visualizations support your answer.

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2. Does one hemisphere receive more incoming solar energy during its summer? Which one? In your answer, use both qualitative terms (e.g., more than, less than) and quantitative (e.g., a difference of 100 watts per square meter).

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3. Why might that hemisphere be getting more solar energy? The following picture of the Earth's location relative to the sun during the solstices and equinoxes can help you figure this out.

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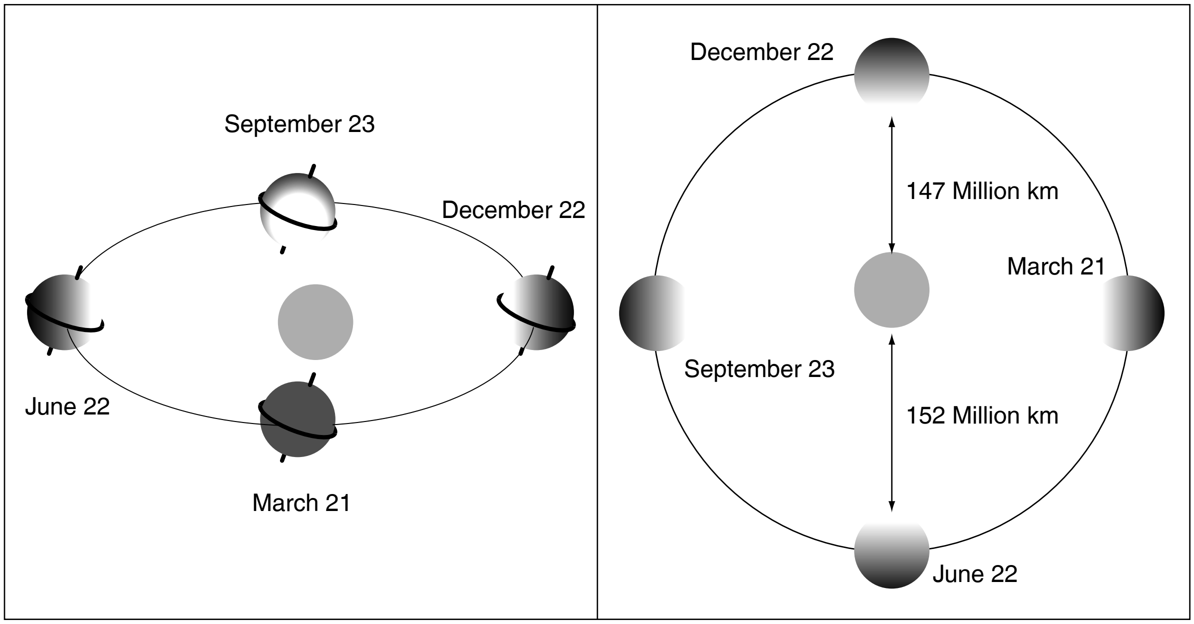
Earth's Location Relative to the Sun



4. Now look at the visualizations of Earth's surface temperature in January and July (Figure EA-S5-2 or *Work Sheet 2*). In particular, compare the areas of land and water around the poles. Which hemisphere seems to have a colder winter? (Northern/Southern) A warmer summer? (Northern/Southern) Describe the evidence you found in the visualizations that helped you decide.

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5. Compare your answer for question 2 to your answer for question 4. Is the hemisphere that gets more incoming solar energy in the summertime the one that has the warmer summer?

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Suggest a reason for this and then do the rest of the *Work Sheet* which will help you explore the reason.

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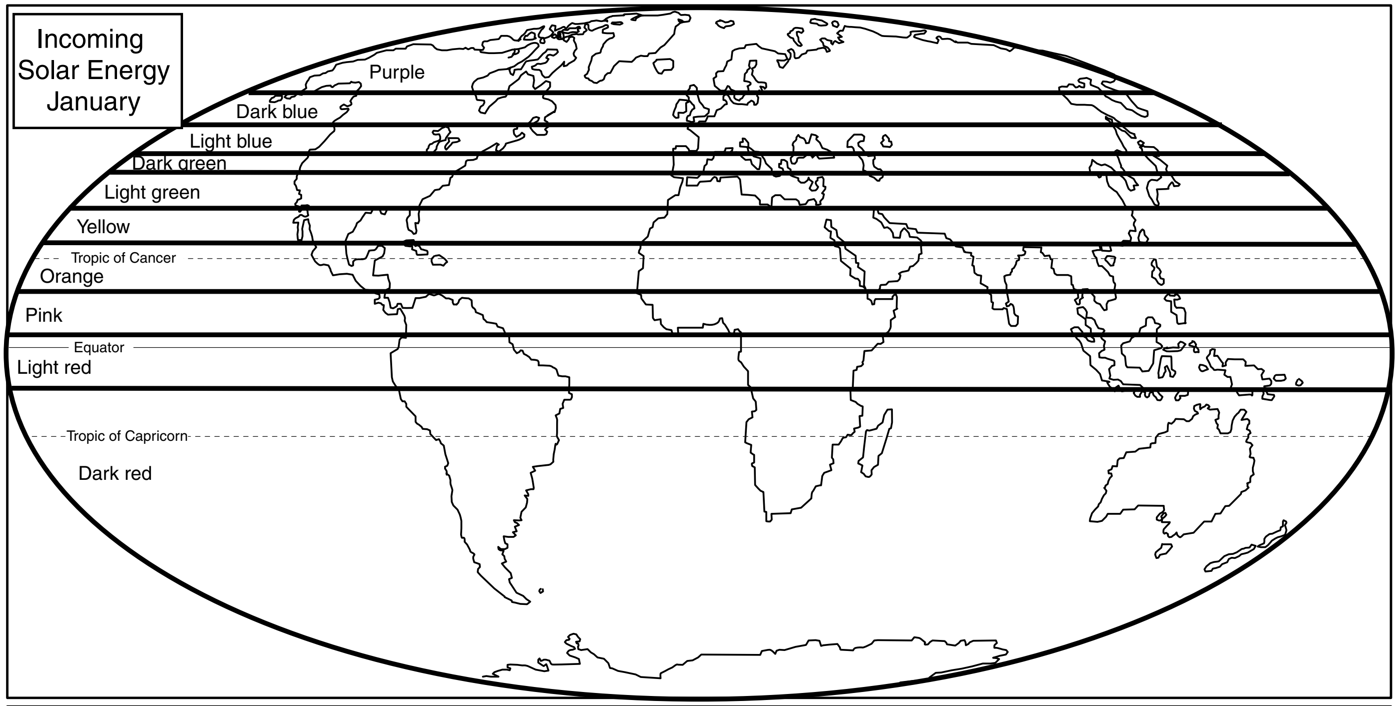
Name: ______________________________

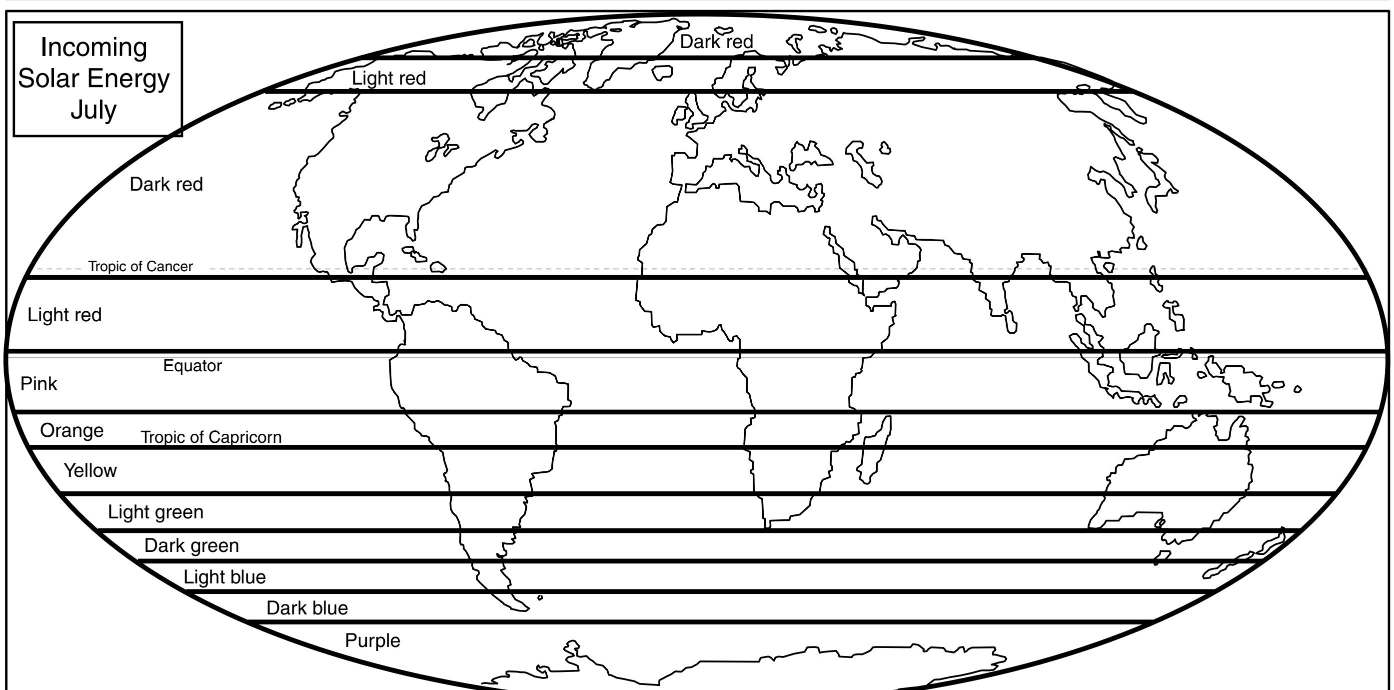
Work Sheet 1: Average Incoming Solar Energy for January and July

Directions: Color in the incoming solar energy bar and the visualizations for incoming solar energy for January and July. Use the color indicated and color in between the bold lines.



Incoming Solar Energy
Units: Watts/meter sq.

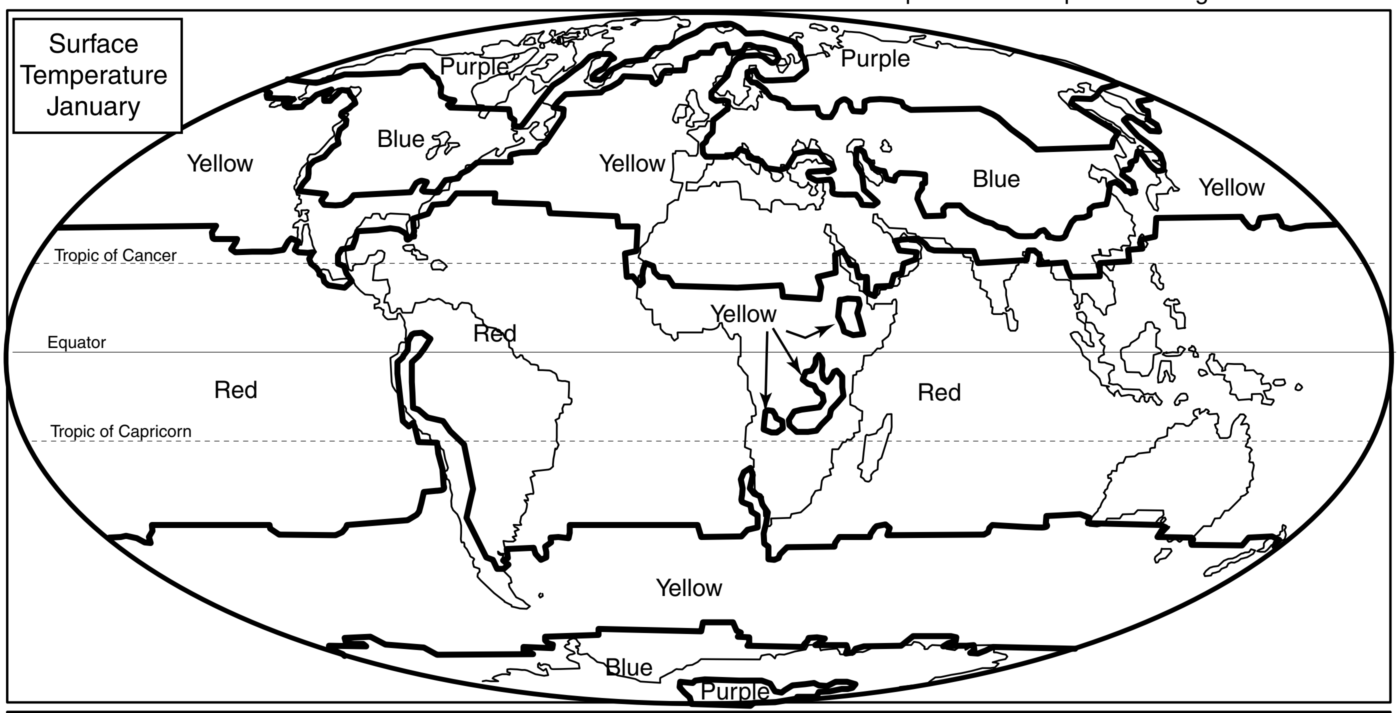
0–50	50–100	100–150	150–200	200–250	250–300	300–350	350–400	400–450	450–500
Purple	Dark blue	Light blue	Dark green	Light green	Yellow	Orange	Pink	Light red	Dark red



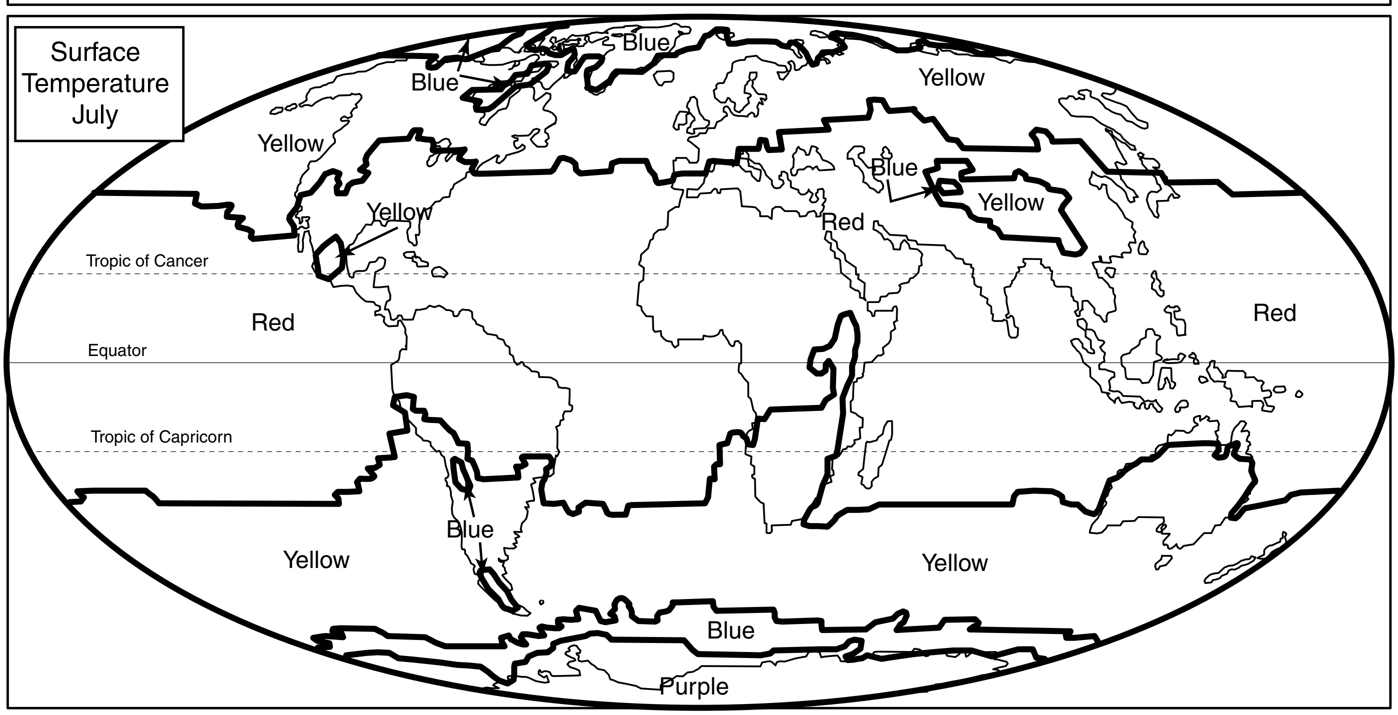
Name: ____________________

Work Sheet 2: Average Earth Surface Temperatures for January and July

Directions: Color in the temperature bar and the visualizations for Earth surface temperature in January and July. Use the color indicated and color in between the bold lines. Each color represents a temperature range.



-40 C	-20 C	0 C	20 C	40 C
Purple	Blue	Yellow	Red	



6. Consider the difference in temperatures between summer and winter in each hemisphere.

A. Figure EA-S5-3a (or *Work Sheet 3a*) shows a visualization of the January to July temperature ranges around the world: the shade of blue tells you how many degrees difference there is between the average monthly temperatures in January and July. If the temperature difference is large, the color is darker, and if the difference is smaller, the color is lighter. Beijing, China and Melbourne, Australia are at similar latitudes, but in opposite hemispheres, and they have very different temperatures ranges. Quantify the difference by analyzing the visualization and give reasons for the difference.

B. If you're having trouble deciding on a reason for the difference, think about the size of the continent the two cities are on. Which would you expect to heat or cool faster, Australia or Asia? Why?

C. How does your answer to question B about which continent heats faster relate to question A, which asks about the difference in temperature?

7. Finally, generalize your analysis to compare the Northern and Southern Hemispheres as a whole. Which hemisphere has the hotter summer and colder winter, Northern or Southern? Explain your answer and give reasons for the difference, using evidence to support your argument. Use the data shown in the visualizations in Figures EA-S5-1, 2, and 3 (or *Work Sheet 1, 2,* and *3*) as evidence. You may also refer to Figure EA-S5-3b (or *Work Sheet 3b*) which shows the amounts of land and water in the two hemispheres.

Name: ____________________

Work Sheet 3: Land Mass Distribution and Seasonal Temperature Change

Directions: The top visualization is of seasonal surface temperature difference, or, the bottom drawing minus the top drawing in Work Sheet 2. Color in the color bar and the Seasonal Temperature Change visualization using the colors indicated.

Figure EA-S5-3a: Seasonal Temperature Range

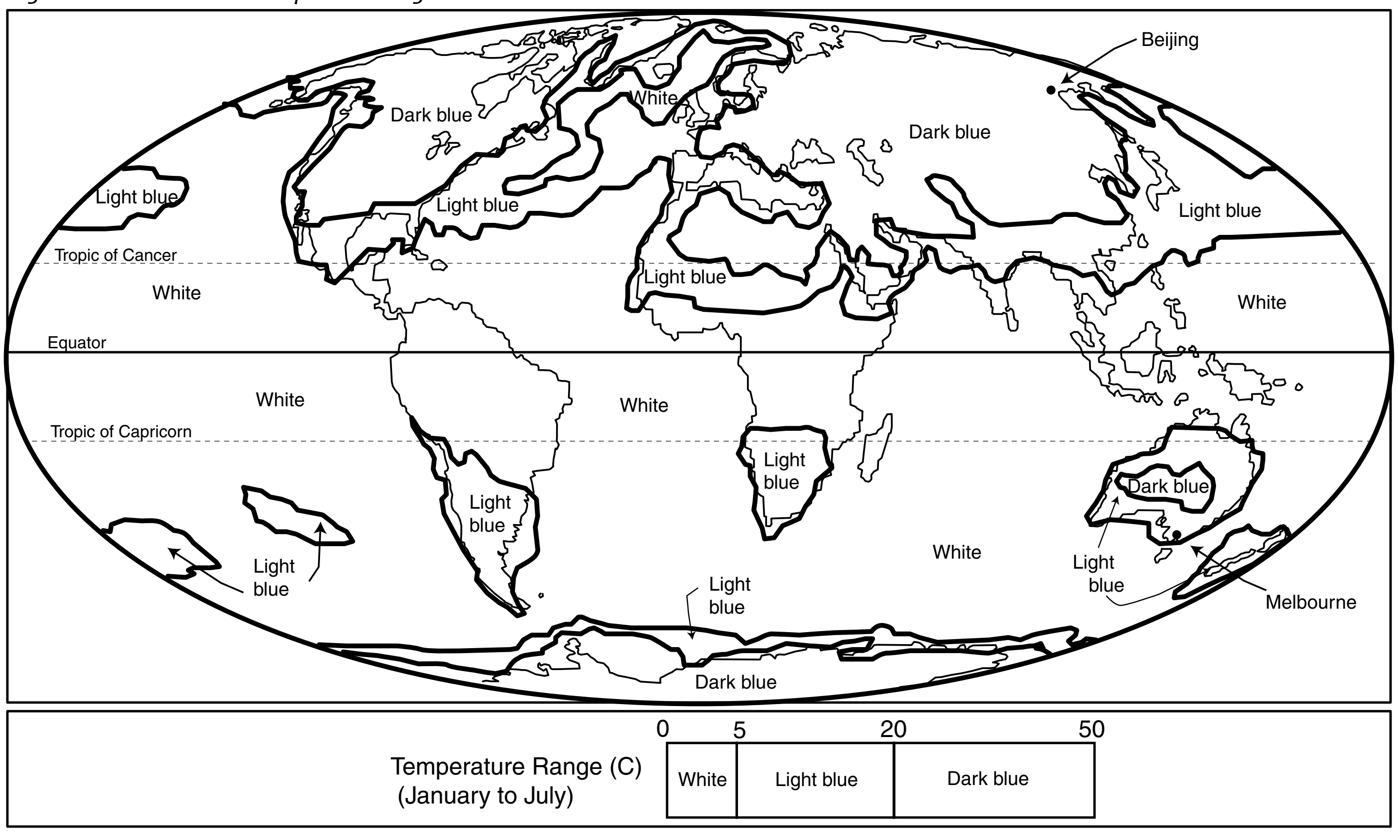


Figure EA-S5-3b: Area of Land and Water by Hemisphere

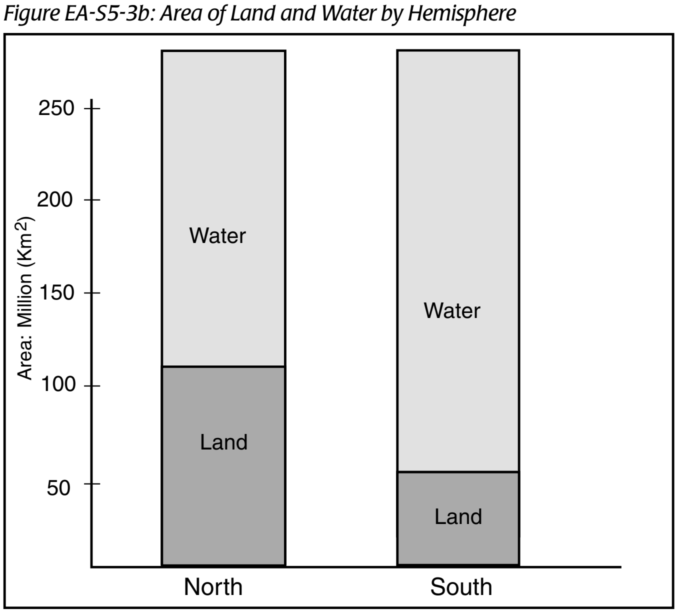
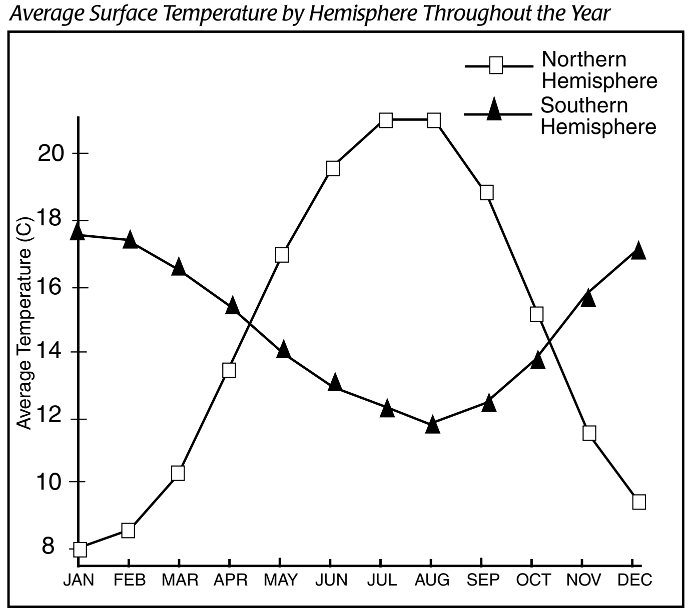


Figure EA-S5-3c:
Average Surface Temperature by Hemisphere Throughout the Year



Seasonal Change on Land and Water

Rubric

For each criterion, evaluate student work using the following score levels and standards.

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, but needs improvement

0 = Answer is blank, entirely arbitrary or inappropriate

1. Use evidence from the incoming solar energy visualizations to conclude which hemisphere has the summer in January and which in July.

Score Level	Description
3	Student states that the visualization for January shows more color in the orange to red range for the Southern Hemisphere, indicating it is summer there. The same is true for the Northern Hemisphere in the visualization for July.
2	Hemisphere answer is correct, and indicates that colors in visualization show this, but does not discuss colors or what they indicate.
1	Answer is correct but fails to refer to visualization for evidence.
0	Answer is blank or irrelevant.

2. Compare relative amounts of incoming solar energy during summers.

Score Level	Description
3	Student gives the correct answer that the Northern Hemisphere has more solar energy during its summer, and explains that the visualization shows more dark reds. Student quantifies their answer by suggesting that the overall values for summer in the Northern Hemisphere are around 500 watts/meter sq. and are around 450 for the Southern Hemisphere.
2	Gives correct answer, but one explanation (either quantitative or qualitative) is missing.
1	Answer is correct but fails to refer to visualization for evidence.
0	Answer is blank or irrelevant.

3. Understanding how Earth's orbit around the sun can explain solar energy data.

Score Level	Description
3	Student notes that the Earth is closer to the sun in December than in June.
1	Student refers only to the Earth's tilt and fails to suggest distance as a reason.
0	Answer is blank or irrelevant.

4. Use evidence from the temperature visualizations to conclude which hemisphere has a colder winter and which a warmer summer.

Score Level	Description
3	Student correctly answers Northern for both, and describes that the visualizations of temperature show that the Northern Hemisphere, in January, has more blues which indicate temperatures below freezing, and that in July the visualization shows more dark reds which indicate temperatures around 30°-40°C.
2	Hemisphere answer is correct, and indicates that colors in visualization shows this, but does not discuss colors or what they indicate.
1	Answer is correct but fails entirely to refer to visualization for evidence.
0	Answer is blank or irrelevant.

5. Preliminary conclusion that the hemisphere experiencing the warmer summer actually has less incoming solar energy during that time than the summer of the other hemisphere.

Score Level	Description
3	Student answers no and suggests something to do with landmass, or offers other reasonable suggestion.
1	Student answers yes or no but offers no suggestion why.
0	Answer is blank or irrelevant.

6. Analyze temperature range visualization to understand how land mass influences temperature.

Score Level	Description
3	Student is able to interpret the visualization to quantify the temperature ranges for 6A. For 6B, the student answers that Asia will heat and cool faster. For 6C, student connects the size of the continents with the difference in temperature.
2	Some combination of correct and incorrect answers for A-C.
1	Student answer fails to offer correct quantitative ranges or reasoning for 6A, states incorrectly that Australia is the answer for 6B, and does not connect continent size with temperature difference for 6C.
0	Answer is blank or irrelevant.

7. Student generalizes answer to 6 to whole hemisphere.

Score Level	Description
3	Explanation mentions that since the Northern Hemisphere has more land and land has a lower heat capacity (it heats up and cools down more quickly than water), it produces colder winters and warmer summers. Alternatively, the student could state that the Southern Hemisphere has more water than the Northern Hemisphere and since water has a higher heat capacity it leads to less cooling in the winter and less warming in the summer (i.e., less change overall).
2	Answer incorporates the idea of land distribution, but fails to note that land and water have a different heat capacity (seasonal temperature variation).
1	Answer focuses on differing amounts of incoming solar energy between hemispheres, closeness of Earth and sun, or other incorrect explanations.
0	Answer is blank or irrelevant.

P1: Green-up Cards

Purpose

To recognize patterns of green-up at the plant, landscape and regional scales

Overview

This activity is to prepare students to recognize what a bud looks like and the progression of green-up from the time of budburst. Students will arrange plant growth pictures taken from the bud, shrub canopy, grass clump, landscape and regional perspectives.

Student Outcomes

Students will recognize temporal (over time) progression of green-up at the bud, shrub canopy, grass clump, landscape and regional spatial scales.

Science Concepts

Earth and Space Sciences

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Life Sciences

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Plants and animals have life cycles.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

The population of an ecosystem is limited by its resources.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

The interaction of organisms in an ecosystem have evolved together over time.

Scientific Inquiry Abilities

Observing patterns at different scales

Ordering observations

Use appropriate tools and techniques.

Time

One class period

Level

All

Materials and Tools

Green-up cards

GLOBE Student Science Log

Preparation

None

Prerequisites

None

Background

This activity is to help students know what to look for when they start the Green-up Protocol observations which will provide ground verification of remotely sensed images. This will also help students appreciate the variety of spatial scales at which green-up occurs. To help prepare students for the *Green-up Protocol*, pictures of green-up and leaf growth are provided. By using Green-up Cards, they will identify green-up patterns at the bud, shrub canopy, grass clump, landscape, and regional (remotely sensed) spatial scales.

Spatial scale refers to gradations of area size (from square centimeter to square kilometer) of space viewed. Each scale is a foundation for the next scale, as can be seen in the table below.

Trees/ Shrubs	Grasses
Bud	Grass blade
Branch	
Tree/Shrub	Grass clump
Community	Grass field
Region	Region

Unique patterns of green-up can be observed within each scale and the patterns within scales are related. Buds (small, hard, protective structures containing miniature leaves formed every year by trees and many other plants in preparation for the next growing season), though seemingly small and insignificant, become more important from a global perspective related to green-up as the scale increases to regional spatial scale. Regions are composed of landscape units. Landscapes are composed of shrub and tree communities, and grass fields. At the landscape scale, migrations of waterfowl, songbirds, mammals and other wildlife are connected to the patterns of green-up. Green-up is important for the ecology of these organisms because it indicates availability of favorable conditions to provide food and shelter for these migratory animals. At the regional scale, scientists are using satellite images to observe green-up and to make greenness maps for use in assessing fire danger in savanna areas of Australia, Africa, and the United States. High greenness areas represent lower wildfire danger, while low greenness areas represent higher wildfire danger.

What To Do and How To Do It

Getting Ready

- To help understand students' thinking before the activity, ask students what a bud is and why they think buds are important in green-up.
- Ask students why they think observing green-up is important.
- Ask students in what other spatial scales green-up occurs besides the bud level, and why they think the different scales are important.
- Ask students what factors might be important in initiating green-up (warmer temperatures, increased soil moisture, etc.) and why they think so.

Exploration

- If there are not enough sets of green-up cards so that each student can have a set, have students get into groups.
- Pass out a set of green-up cards for each group.
- Ask each group to arrange the green-up cards in an order that makes sense to them to show progression of green-up with time (from beginning of green-up to leaf maturity) and at different spatial scales: bud, shrub/tree, grass clump, landscape, and regional (remotely sensed). Tell them to be prepared to talk about what they did.

Generalization

- Ask students to share what they did and why.
- Ask students what they understand about spatial scale
- Ask students to discuss importance of observations on smallest scale, e.g., bud or grass blade level.

Assessment

1. GLOBE Student Science Log
   Have students write and/or draw in their logs about
   - What a bud is and why they think buds are formed.
   - Why observing and recording green up is important.
   - At what scales green-up occurs and the importance of the different scales.
   - Have each student predict the date that green-up will occur this year at their school study site and explain why he/she chose the date. (Is it based on environmental factors that bring about green-up?)
2. Have students arrange green-up cards to show progression of green-up over time (from beginning of green-up to leaf maturity) and at different spatial scales: bud, shrub canopy, grass clump, landscape, and regional (remotely sensed).

The card sets with examples of different spatial scales are in the following figures.

Examples From the Bud Scale

Aspen :

Cards A

Card B

Card C

Card D

Card E

(photographs with line drawings)

Birch :

Cards A

Card B

Card C (photographs with line drawings)

Willow:

Card A

Card B

Card C

Card D

(photographs with line drawings)

Examples from the grass clump scale:

Card A

Card B

Card C

(photographs and line drawings)

Examples from the shrub canopy scale:

Card A

Card B

Card C

(photographs and line drawings)

Examples from the landscape scale:

Card A

Card B

Card C

Card D

(photographs and line drawings)

Examples from the regional scale:

Card A

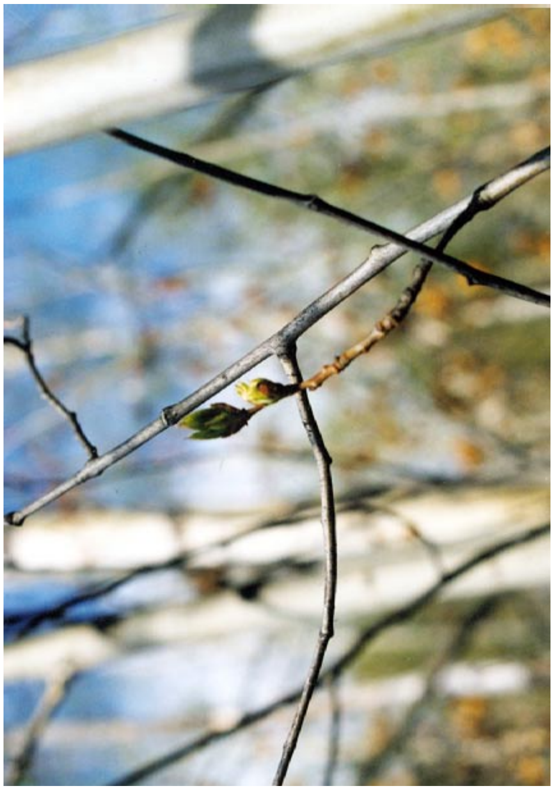
Card B

Card C

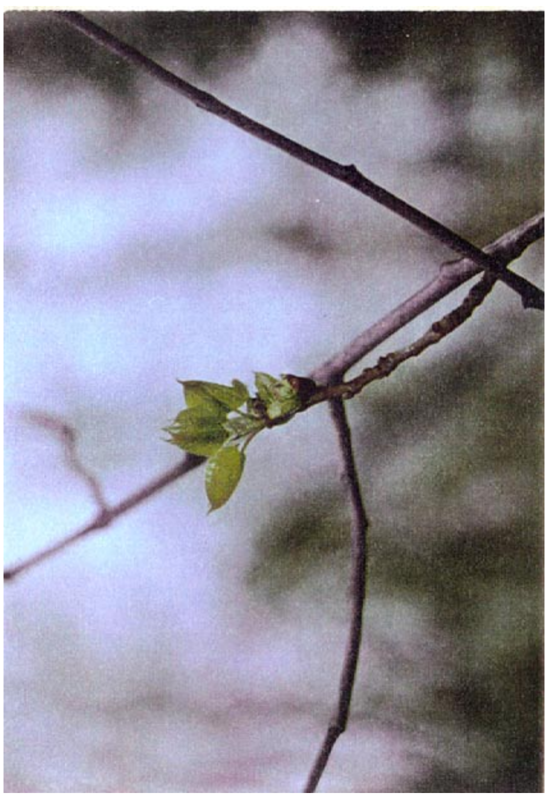
Card D

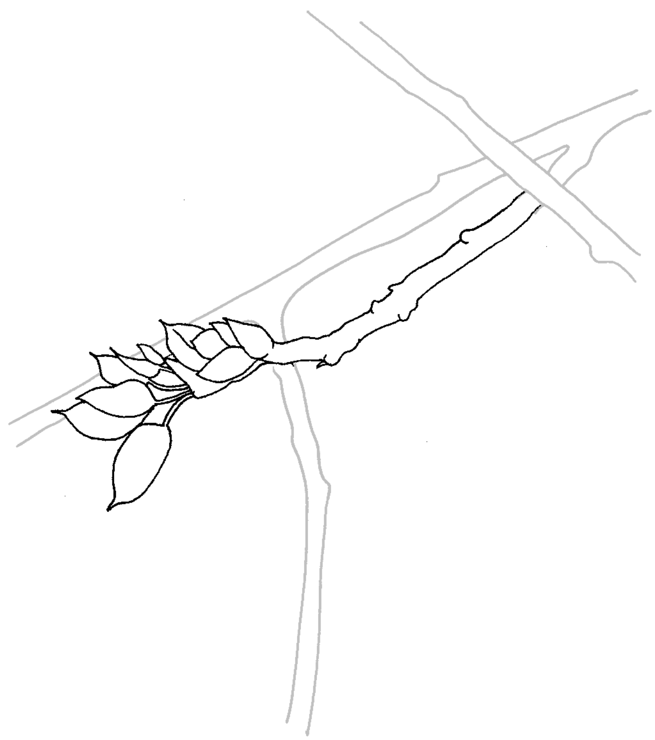
Card E

Aspen B

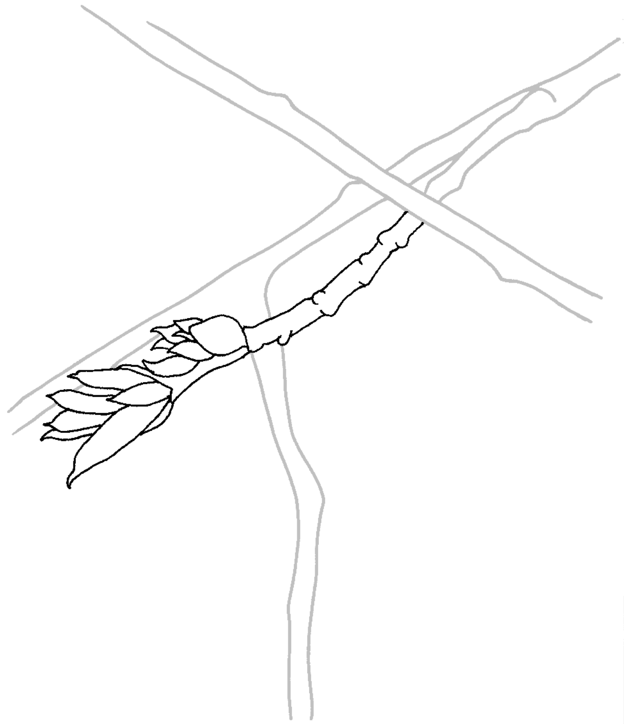


Aspen A

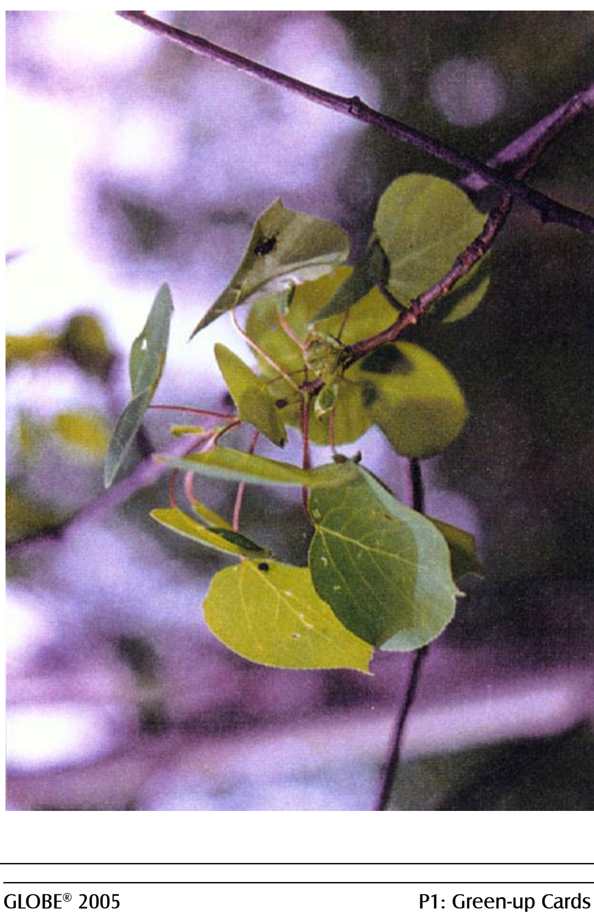


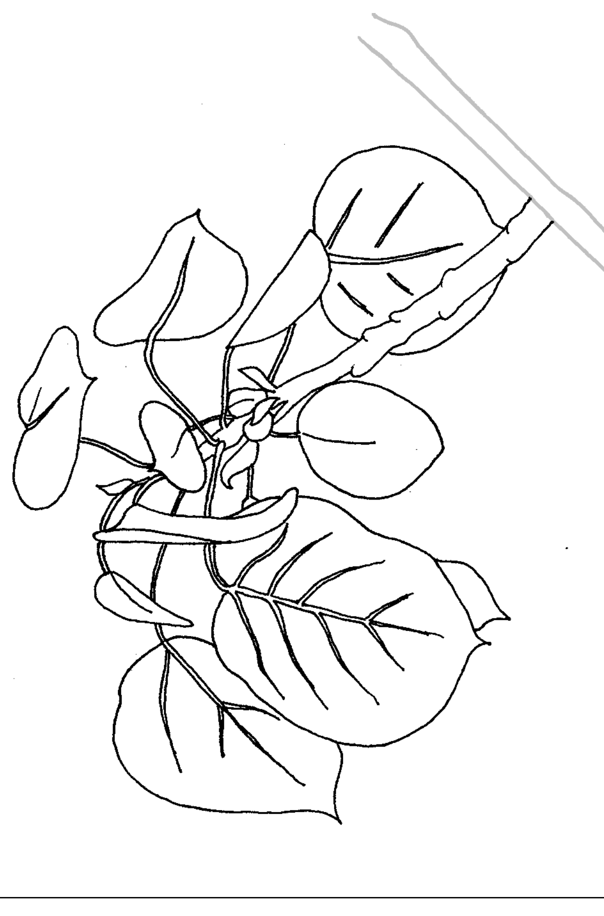


Aspen D

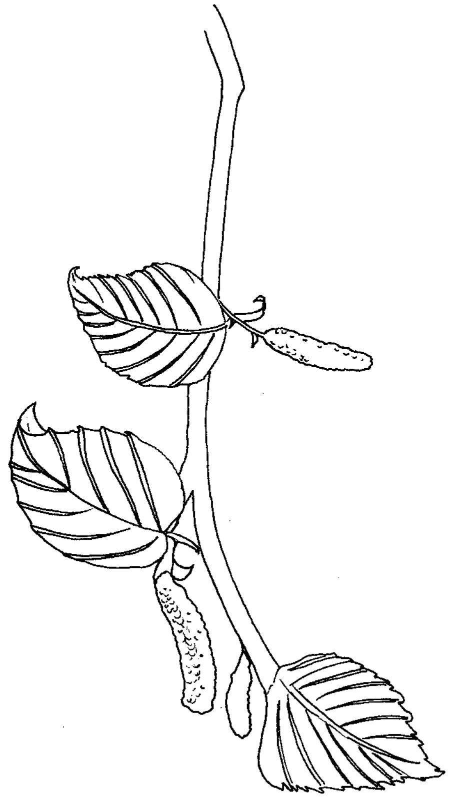


Aspen C



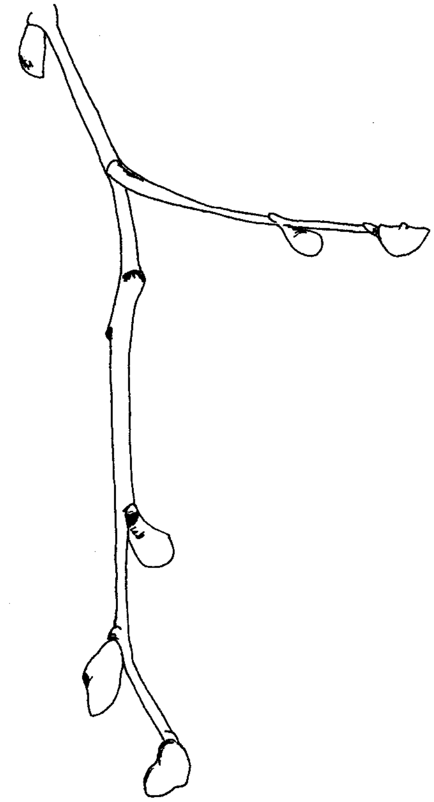


Birch A

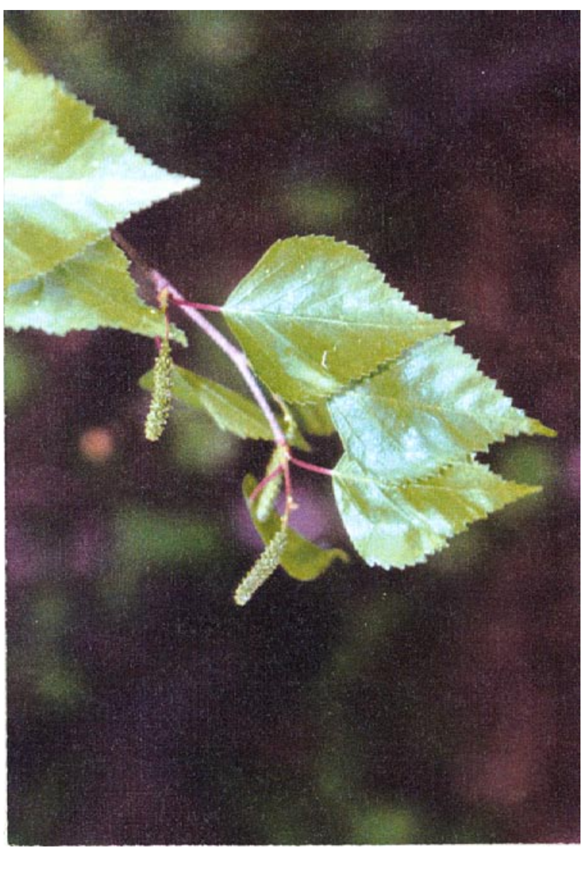


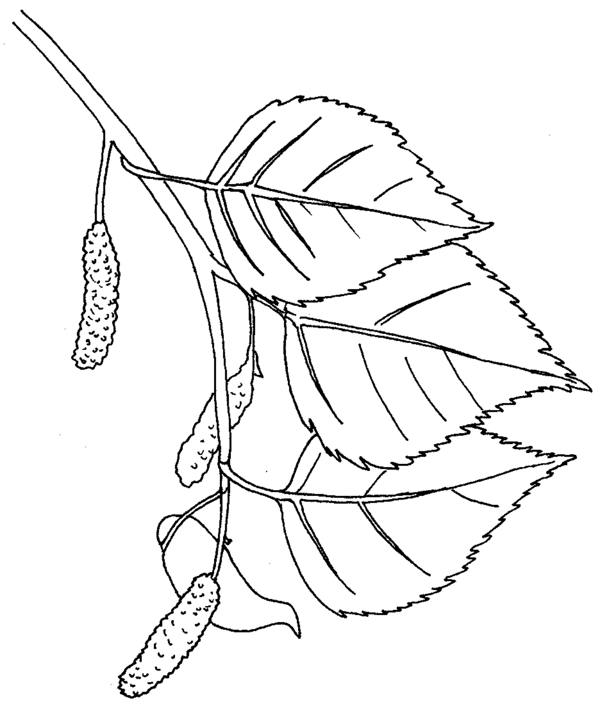
Aspen E

Birch C

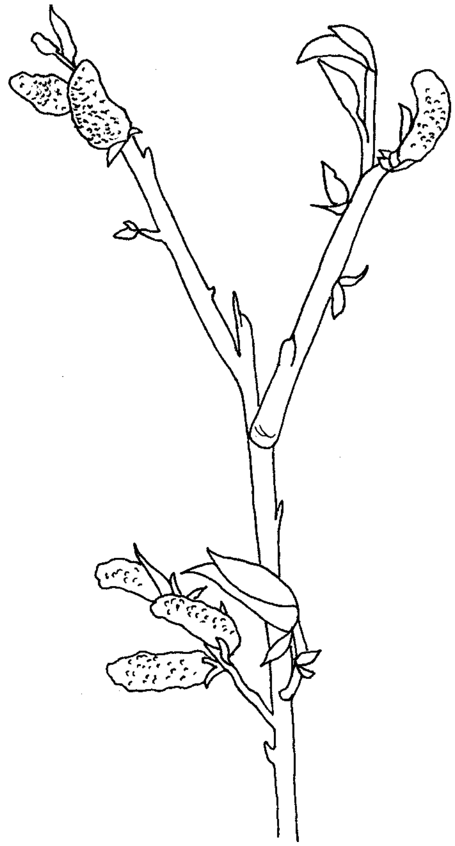


Birch B

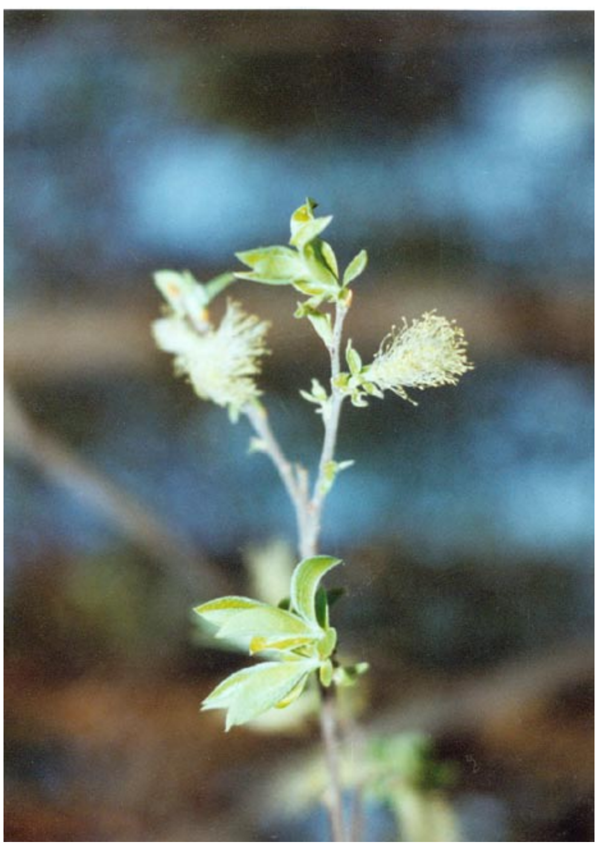




Willow B



Willow A



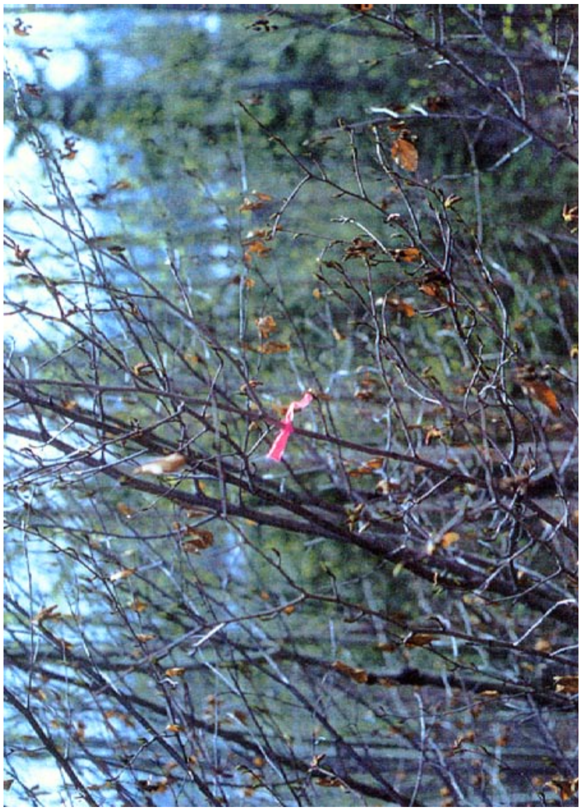
Willow D

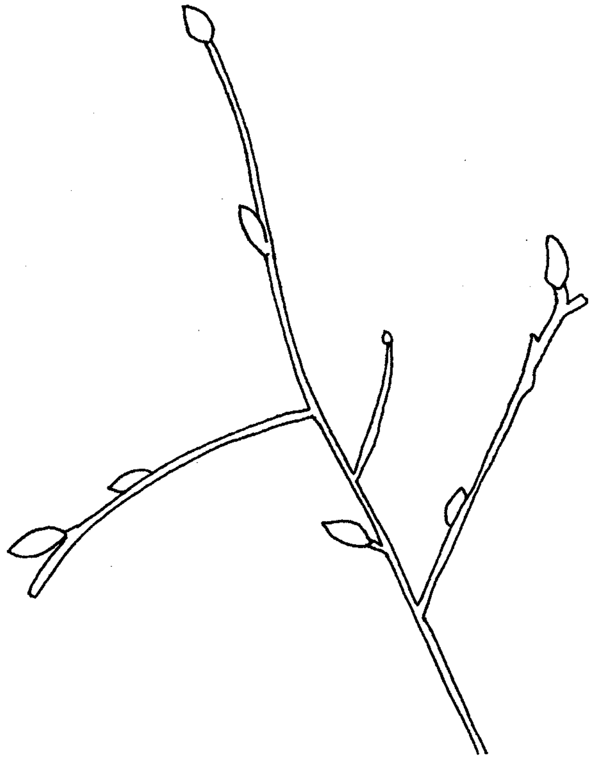
Willow C

Grass Clump Scale B

Grass Clump Scale A

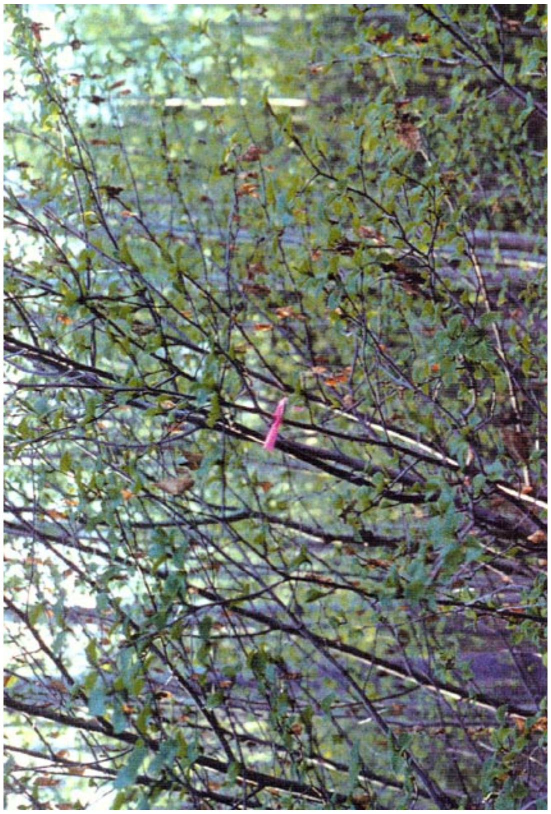
Shrub Canopy Scale A

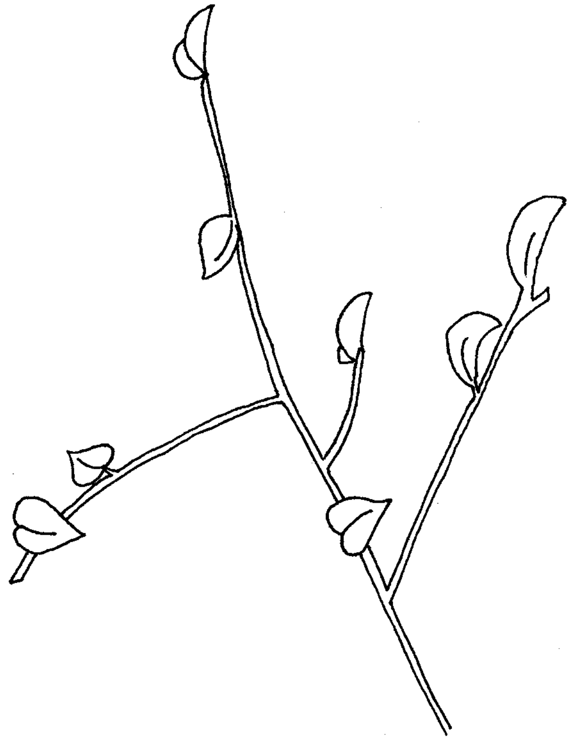




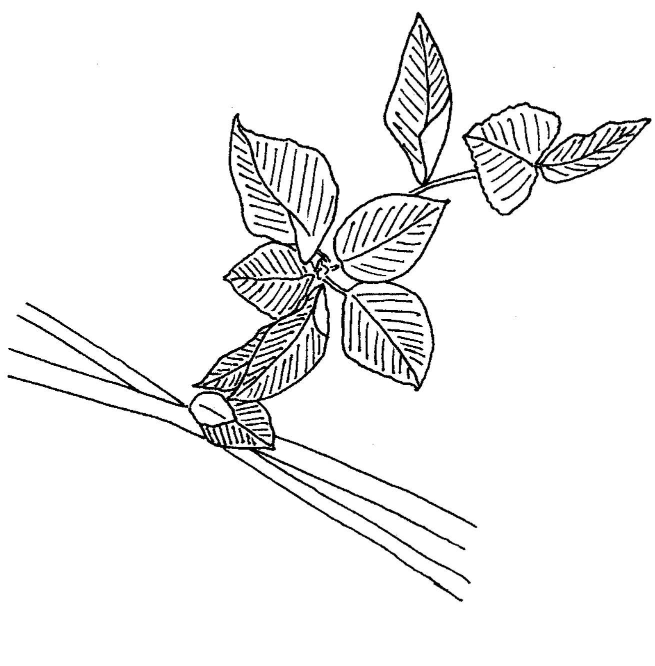
Grass Clump Scale C

Shrub Canopy Scale C



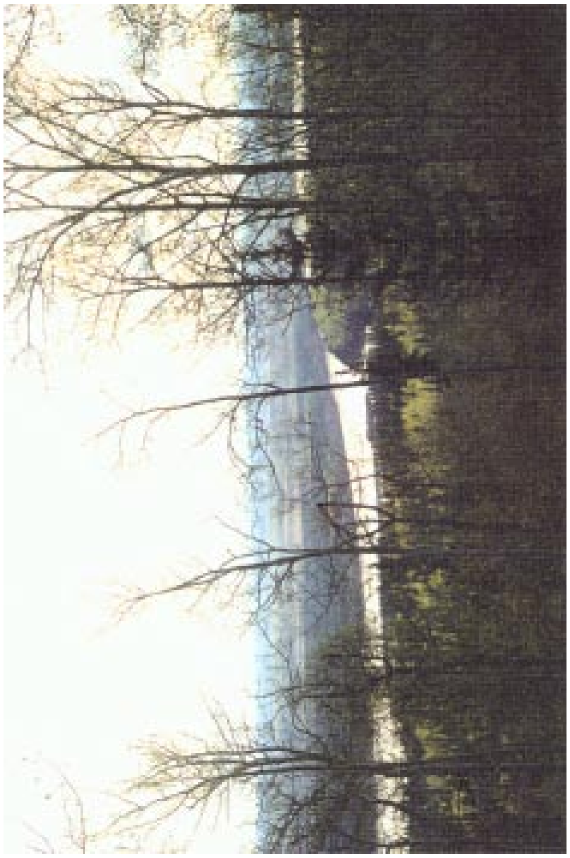


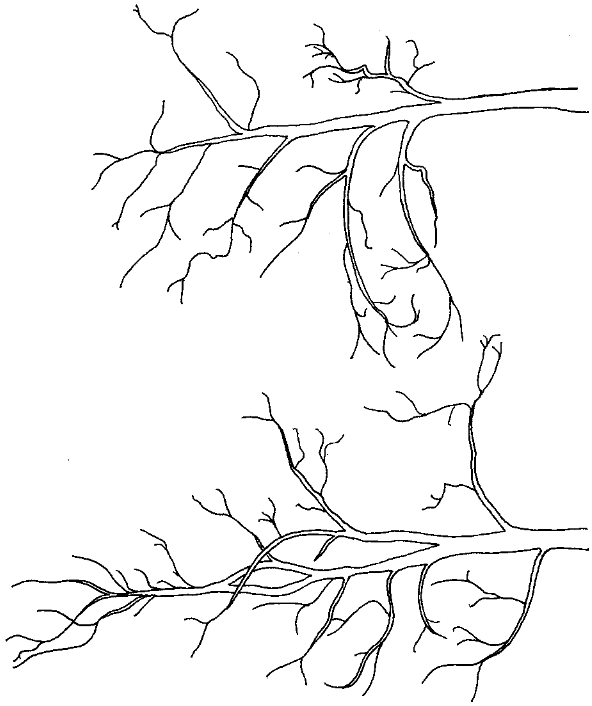
Shrub Canopy Scale B



Landscape A

Landscape B

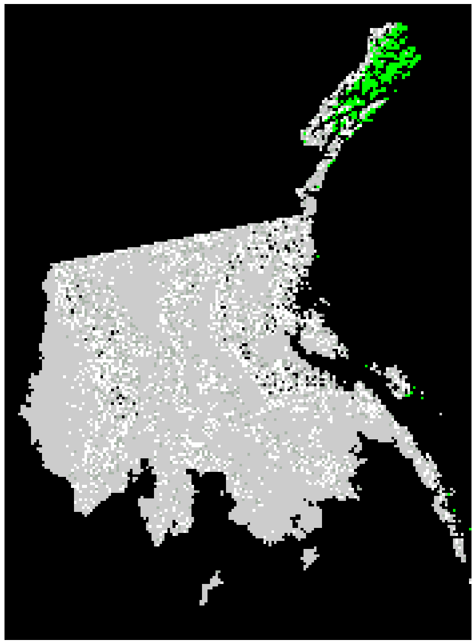




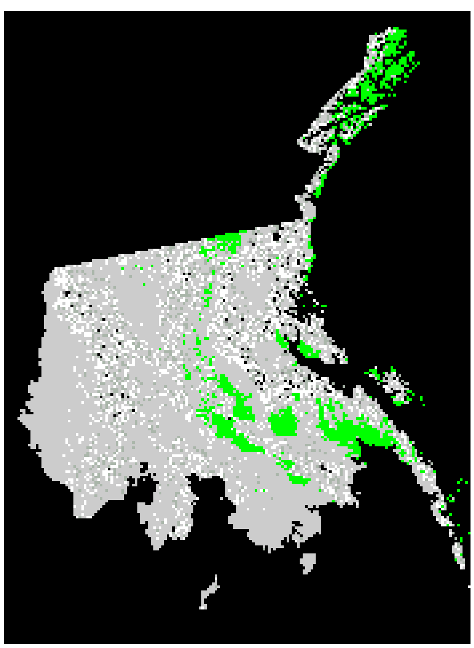
Landscape C

Landscape D

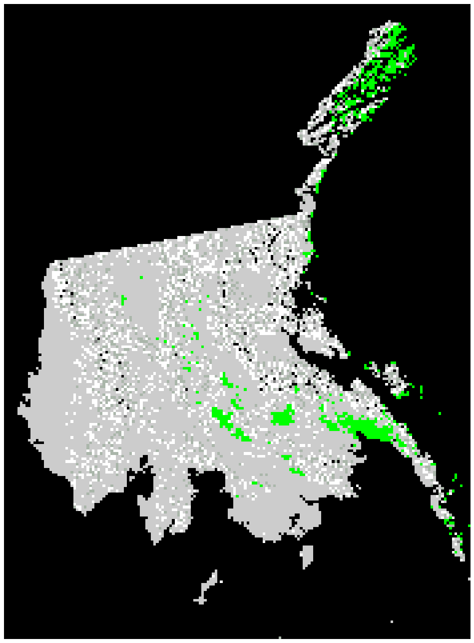
Regional Scale B



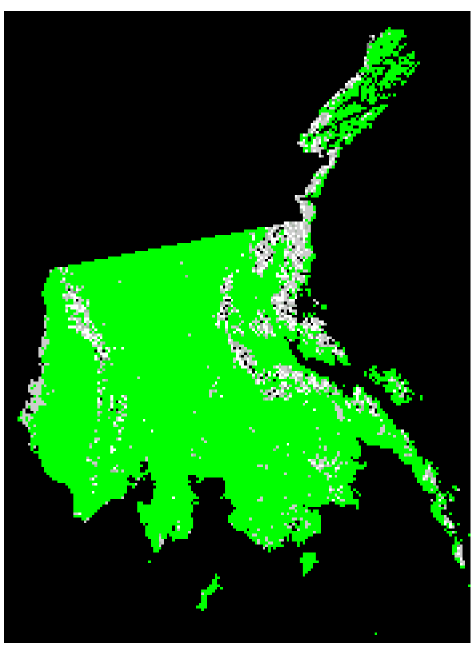
Regional Scale A



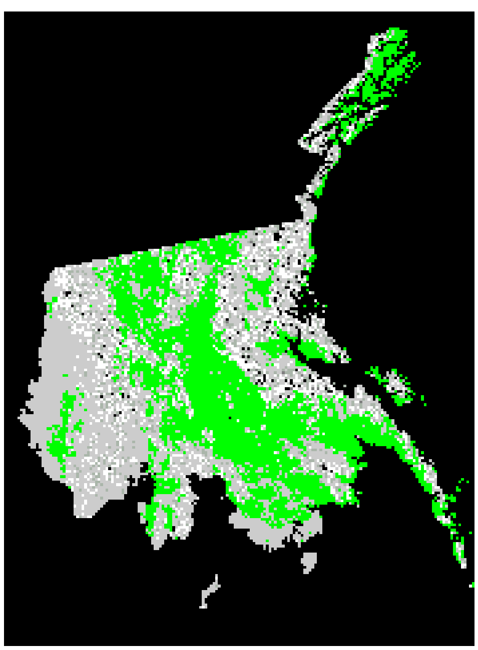
Regional Scale D



Regional Scale C



Regional Scale E



P2: A Sneak-Preview of Budburst

Purpose

To develop an understanding of the relationship between budburst and the environment

To help students recognize actual budburst when they are doing the *Green-up Protocol*

Overview

Students will do simple explorations to observe the relationship between budburst and temperature. This is a winter or dry season activity to be done prior to green-up observations.

Student Outcomes

Students recognize budburst and understand time of budburst is affected by factors such as temperature, moisture and plant species.

Science Concepts

Earth and Space Sciences

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation.

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Chemical reactions take place in every part of the environment.

Life Sciences

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non living components of the ecosystem.

Energy flows through the ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers).

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Observing

Inferring

Predicting

Collecting data

Analyzing data

Use appropriate tools and techniques

Time

One full class period and a number of short sessions to check buds daily or every other day and record observations in GLOBE Science Logs

Level

Beginning and Intermediate

Materials and Tools

Twigs or small branches cut from a variety of dormant broadleaf shrubs or trees (cut and placed in water the night before)

Containers of water

Light source

GLOBE Science Log

Prerequisites

None

Background

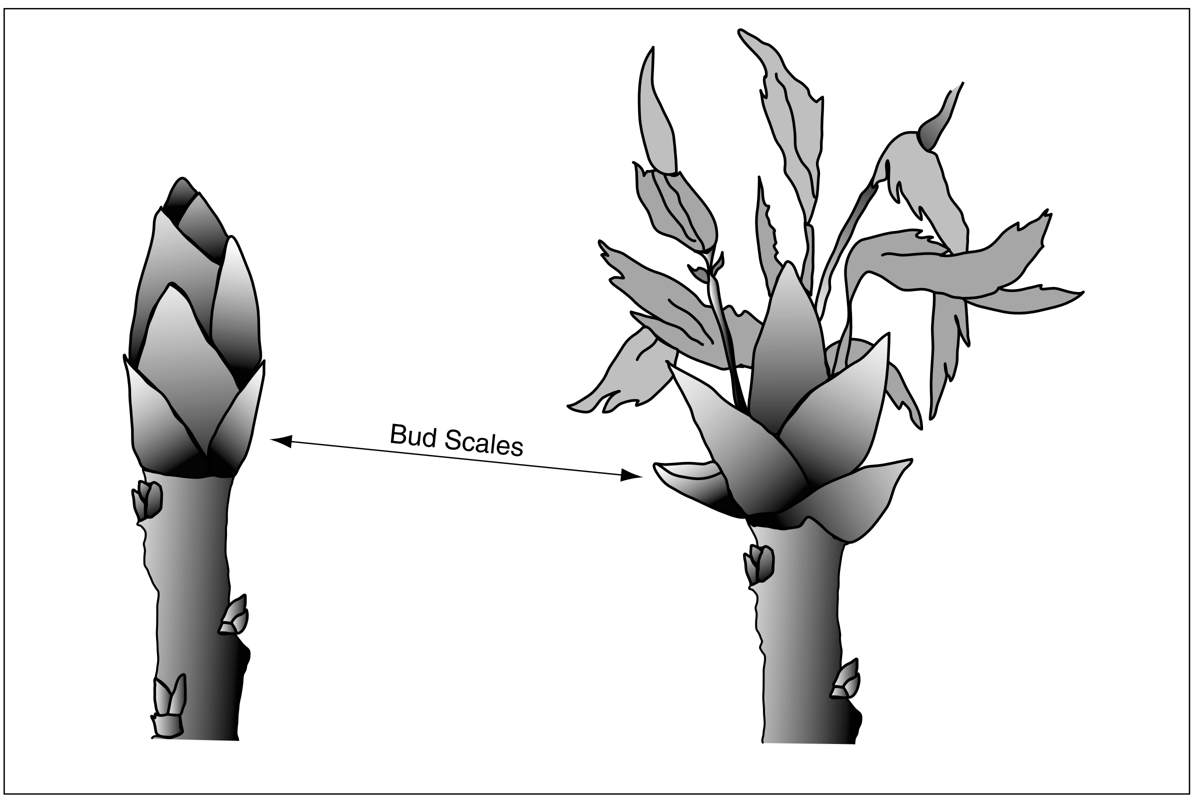
What are buds and why are they formed?

Buds are small, hard, protective structures containing miniature leaves. Budburst is an example of a phenological occurrence. In the fall, short days and decreasing temperatures trigger the cessation of growth in deciduous trees and shrubs, the drop of leaves, and the onset of dormancy, similar to the hibernation of animals. *Dormancy* is a state of suspended growth and metabolism. When plants become dormant, growth stops due to a growth inhibiting substance, the liquid and food-laden sap stops flowing, and each branch's tender growing tip is carefully enclosed in a tight bud. The buds protected by layers of bud scales, are formed every year by trees and many other plants in preparation for the next growing season.

Why do buds open?

These buds stay closed through the cold or dry season and burst open with the return of rains or warmer temperatures breaking plant dormancy. This opening is called budburst or bud break, and is easy to detect. Buds open and new leaves begin to expand. Hence, the timing of budburst is influenced by temperature or moisture. Trees

Figure EA-P2-1: Tip of Deciduous Tree Stem Enclosed in a Bud Protected by Bud Scales



can be awakened from dormancy by being warmed, exposed to a minimum time of 300 hours, at temperatures near 25˚C. Plant roots start absorbing water and transport these along with stored food within the plant to other plant parts including buds or shoots. Plant leaves start to come out, make chlorophyll to capture light energy and begin to photosynthesize or make food using carbon dioxide from the air, light and water. See background for *A Beginning Look at Photosynthesis: Plants Need Light Learning Activity*.

What To Do and How To Do It

Getting Ready

- Show the students the branches from local shrubs/trees that you have selected
- Ask students what budburst is and what they think causes budburst in plants?
- Ask them what makes them think so?
- Ask students to predict if they think all the branches/twigs will burst at the same time? Why or why not?
- Have them predict in what order they think the buds will burst.
- They should enter both predictions in their GLOBE Science Logs.

Explore

Have students get into groups. Pass out branches/twigs to students. Try to be sure that each group has a variety of branches. Have students put the plants in water. Ask them to begin their GLOBE Science Log entries by drawing a line down the center of one of the pages. They should record their observations, inferences, and predictions on the left of the page and draw their observations on the right. Remind students to keep the water full in their containers. Give students time daily to record their observations in their GLOBE Science Log until several days after budburst is complete.

Generalize

- After budburst occurs, ask students to share their observations.
- Ask students to list all the ways the plants changed when they were brought into the classroom.
- Ask students why they think the buds burst when the branches/twigs were brought into the classroom. What were the variables (environmental conditions) that changed as branches were brought in? List variables.
- Ask students if they have any ideas about what might be going on inside the plant to cause the budburst. Discuss. For primary students, help them understand that many things (variables such as temperature, water and kind of plant) affect what buds do in the classroom. For intermediate students, ask them whether it is a good idea to set up a controlled experiment (changing only one variable or factor at a time and keeping others constant) and why. (The reason for the controlled experiment is to be able to determine which factor affects timing of budburst). Discuss possible experiments they could do (different temperatures for same plant species, all twigs in water, different plant species at one temperature with all twigs in water, etc.) but let students come up with their own ideas first.

Assessment

GLOBE Science Notebook Entry

Have students write and/or draw in their GLOBE Science Log about:

- What changes occurred when the plants came into the classroom
- Why they think the changes occurred
- The similarities and differences among the branches/twigs.
- Students who have difficulty writing can be interviewed for understanding.

Students will recognize budburst of trees/shrubs and record correct date on the green-up data sheet when it occurs during the *Green-up Protocol*.

Assessment Rubric for Students' Entries in their GLOBE Science Log

Exceeds Standards: Student clearly articulates what changes occurred in the plant branch over time, using good observation skills and states reasonable explanation for why changes might have occurred.

Meets Standards: Student clearly articulates what changes occurred in the plant branch over time, using good observation skills; explanation for why changes might have occurred is not reasonable.

Needs Improvement: Student does not clearly articulate what changes occurred, observations are poor and explanations are not reasonable.

P3: A First Look At Phenology

Purpose

To increase students' awareness of qualitative changes in plant(s) during green-up and green-down from which they will be collecting quantitative leaf change data

To develop an understanding of the patterns, similarities, and differences among plants at the same location

Overview

Students will observe, compare, and classify plants during green-up or green-down and then make inferences based on the patterns they observe.

Student Outcomes

Students will learn stated science concepts and be able to apply process skills in understanding patterns of green-up and green-down among plants.

Science Concepts

Life Sciences

- Earth has many different environments that support different combinations of organisms.
- Organisms' functions relate to their environment.
- Plants and animals have life cycles.

Scientific Inquiry Abilities

- Observing
- Measuring
- Classifying
- Collecting data
- Analyzing data
- Inferring
- Predicting
- Use appropriate tools and techniques.
- Develop explanations and predictions using evidence.
- Recognize and analyze alternative explanations.

Time

Two to three class periods

Level

Beginning and Intermediate

Materials

- Hand lens
- Survey tape
- Pencils
- GLOBE Science Log
- Plants
- Charts

Prerequisites

None

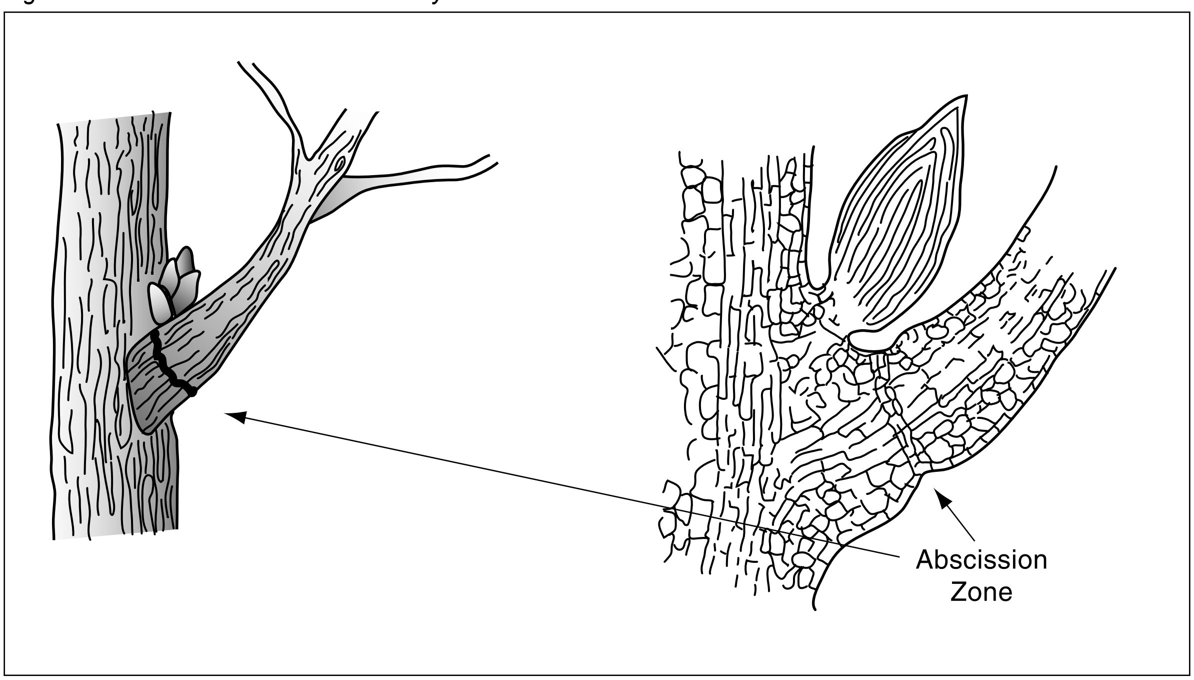
Background

Phenology is the study of organisms' response to seasonal and climatic changes in their environment. Seasonal changes include variations in day length or duration of sunlight, precipitation, temperature and other life-controlling factors. The focus of this activity is plant phenology during green-up and green-down also called senescence. Green-up and green-down can be used to examine regional and global vegetation patterns, year to year variations, and vegetation responses to climate change.

For deciduous trees, bushes, and shrubs the growing season can be defined by the appearance of leaves in the spring and the dropping of leaves in the fall. Plant green-up is initiated when dormancy (a state of suspended growth and metabolism) ceases due to environmental conditions such as longer hours of sunlight, higher temperatures, and increased availability of water. This happens during spring for plants in temperate climates. Plant roots begin absorbing water and nutrients from the soil, and transport these to other parts within the plant including buds or shoots. Growth-inhibiting substances are broken down and replaced by growth-promoting substances. Plant leaves start to come out, make chlorophyll to capture light energy and begin to photosynthesize or make food. With long hours of sunlight and a good supply of liquid water, plants continue to make food in the form of glucose.

In the desert, some plants lose all their leaves and enter into full dormancy during the hottest months when plant parts are most easily damaged by heat and shortage of water. Senescence for non-evergreen plants occurs in autumn. As daylight becomes shorter, temperatures cooler, and water harder to get, plants begin to shut down food production. Deciduous trees like maple, oaks, elms, aspen and birch, shed their leaves in preparation for winter. Many changes occur in deciduous tree leaves before they fall from the branch. At the base of each leaf is a special layer of cells called the *abscission* or separation layer. Through this layer, small tubes pass water into the leaf and food back to the tree all summer. In the fall the cells of the abscission layer begin to swell and form a cork-like material, reducing and finally cutting off flow between leaf and tree. Glucose and waste products are trapped in the leaf. Chlorophyll begins to break down without fresh water to renew it, and the green color of leaves disappears. As the bottom cells in the separation layer form a seal between leaf and tree, the cells in the top of the

Figure EA-P3-1: Leaf with Abscission Layer



separation layer begin to disintegrate. They form a tear-line (making the leaf vulnerable to tearing off the branch) and eventually the leaf falls from the branch.

Loss of leaves in deciduous trees is an essential part of winter cold survival. Plants survive by reducing water loss during winter when water supply is greatly limited, and *acclimation*, a process by which plants become increasingly resistant to subfreezing temperatures without sustaining injury. Evergreens keep most of their leaves during winter and may continue to photosynthesize as long as they get enough water. However, reactions occur more slowly at colder temperatures.

The time of green-up and senescence will vary due to plant species and/or microclimate differences related to plant locations. Similarly, plant appearances (e.g. hue, color, shape, size, etc.) will also vary. It is important for students to practice careful observation of plants and the environment in order to make quantitative observations and in this activity, qualitative observations (using their sense of sight, touch, hearing and smell) on green-up or senescence, leading to generalizations about patterns related to seasonal changes.

Careful observation of characteristics is a prerequisite to classification. Classification is the grouping of things including objects and ideas, according to similar characteristics, and has been used by humans for thousands of years. Many examples of the usefulness of classification in our everyday lives are evident in stores, offices, and homes. Classification is important to all fields of science as well. For scientists, classification helps them organize and understand the natural world. It is a means of learning more about life on Earth and discovering the special relationships that exist between living things. Students can improve their observation and classification skills with awareness and practice of looking closely at objects for details. Careful observation is a foundation of all science and a useful tool for everyday life.

What To Do and How To Do It

Getting Ready

1. After green up or green-down begins, ask students what they have observed happening to plants in the spring (or fall). Create a class list of observations. Ask probing questions to see if anyone understands that there is a variation in bud burst time in the spring and senescence time and color in the fall. Become familiar with the students' prior knowledge so that you can structure learning opportunities that will help them develop more viable conceptions about green-up and green-down, and extend their understandings. Example of questions: Have you noticed a difference in time of occurrence of budburst /changing of leaf color? Do you think plant type or species will affect this occurrence? Are there other factors that might affect timing and patterns of green-up or green-down? How do you think air temperature, available soil moisture, day length will affect green-up or green-down?
2. Ask students why they think observation is such an important skill for scientists. Tell them that for the next activity they are going to have to observe carefully like a scientist would, observing much closer than normal. If there is time model this in the classroom by observing a leaf or branch with one sense at a time. This will help students expand their observations past just looking. Be sure that students understand that careful observation is a foundation of all science.

Exploration

1. Students should observe two different plants species one used for the phenology protocol and a new one at the same study site. It will facilitate comparison if they set up two columns in a page of their GLOBE Science Log, one for each plant. See example.

2. Demonstrate correct use of hand lens. Pass out hand lenses to students and take them outside to their protocol data collection site. This can, but it does not have to be, their Phenology study site. Ask the students to select a new plant (different species, same environmental conditions as other plant) or new plant (same species, different environmental conditions) and mark it with a piece of survey tape.
3. Next have them sit by their plants and observe carefully using their eyes alone first and then their hand lenses, then their other senses, one at a time. Have them record their observations in picture and words, including date and time. Start by observing just one leaf. The object of observation should be at or near the eye level of the student. Try to get the students to focus for at least five minutes. Don't prompt them about what to look for so that you can see how much and what they observe on their own. If students seem to need support in understanding possibilities for using four senses, you might brainstorm ways to collect data for each sense before going out to the field.
4. Have them share their observations back in the classroom, so that all students can benefit from those who looked more closely, in preparation for the next trip outside.
5. Take students out to the site at least two more times during the period of green up or green-down. At the site repeat steps two and three above.

Discussion Questions

1. Ask students to share their observations/comparisons of their plant(s) during green-up or green-down. Encourage all students to ask questions and discuss.
2. Ask them if they have observed any patterns with their plant. Patterns could be from observations of one plant over time or between plants. List on chart paper. Make one chart for "over time" patterns and another for "among plants" patterns.
3. Ask students how their plants are alike and different?
4. Ask students if they can make any inferences (explanations of what they think might be happening based on their observations, etc.) based on their observations of the patterns. A sample response might be "I think that the willow leaves were dying faster because they were turning colors first."

Exploration—Classification

As green up is occurring, partner the students and take them back out to the site. Have them collect ten different leaves from the site representing a variety of sizes, shapes, and colors. Bring them back to the classroom.

For beginning classifiers:

- Have students draw one line down the center of the GLOBE Science Log page, so they can list their observations on one side and their questions on the other.
- Give students ten minutes to observe the ten leaves that they collected. Remind them to use four senses.
- Have students group their leaves into two groups based on their observations. Tell them to be ready to share their labels or attributes with the class when they are called on. Share and discuss, then have them try grouping the leaves with completely different labels.

For more experienced classifiers:

- You may want to start right away with using Venn Diagrams (see example below) or dichotomous keys (see guidelines and examples in *Land Cover/Biology Learning Activities* on Leaf Classification). Tell students that they must include at least one quantitative label (measurement). Have students draw their classification system, such as dichotomous keys or Venn Diagrams, on a large piece of chart paper or newsprint and attach leaves in appropriate places with tape or glue. Share and discuss.

First Look at Phenology Learning Log

Date______________________________ Time____________________________________

Species 1___________________________ Species 2_________________________________

Observe with your four senses (sight, touch, hearing, smell) and a hand lens. Try to use one sense at a time. Describe your observations here in pictures and words.

Leaf 1	**Leaf 2**

Discussion Questions

For beginning students:

- Have students share their classification strategies.
- Ask students what patterns they can observe looking at all the charts. Be sure they notice the timing of green up and senescence.
- Ask students to make inferences based on their observations about why there are variations in timing of green-up or green-down among plants at the same location. Be sure that students understand that timing of green-up and senescence, as well as the colors of senescence, vary among plants at the same location.
- Ask students what questions they have.

For intermediate students:

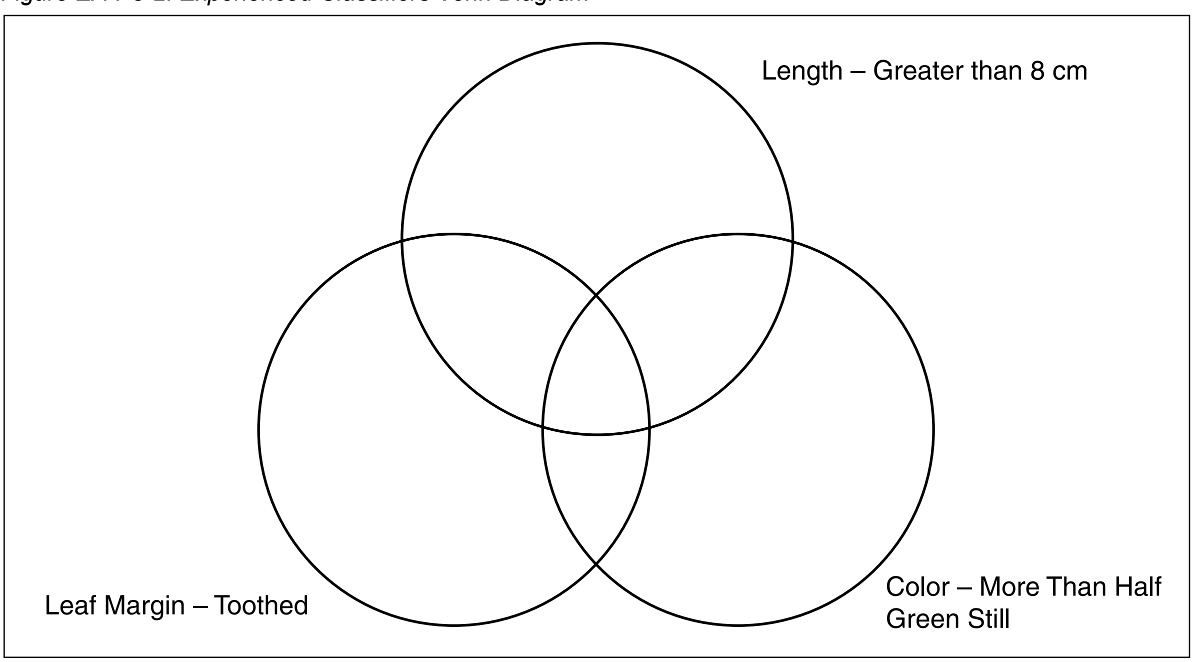
- Ask the class if they can make any statements (generalizations) about leaves during green up/green-down based on their observation of all the leaves. List the statements made. If there are any disagreements, have the group negotiate and reword until everyone can agree on the entire statement. Your goal here is to develop statements that are universal across observations. It may take looking again at the leaves or going back outside to settle debates. Stress that this is part of the scientific process. Compare their list of scientific statements to the list generated at the beginning of the lesson.
- Ask students if they have any ideas about why plants might change with the seasons. At this level it is enough for students to be able to say that they are getting ready for the new season.
- Ask students why they think scientists use classification. How does it help them? How can classification be useful to us in our everyday life? See *Background Materials.*

Further Investigations

For beginning classifiers:

1. Have students try to classify (order) their leaves in a series (sequentially by length, width, surface area, or shades of color, etc.).

Figure EA-P3-2: Experienced Classifiers Venn Diagram



2. Next have the students check their classification by measuring their leaves with a ruler or a centimeter grid for length and width.

For more experienced classifiers:

1. Have students use a professional plant guide to key out their leaves and try to identify them. If possible invite a local plant specialist to confirm their plant identification. Use the *Error Matrix* from *Land Cover/Biology Learning Activities.*
2. Give each group a branch from two local trees or shrubs. Have students come up with a list of attributes to compare how they are alike or different, such as:
   - surface area of leaves
   - firmness or toughness of either branch or leaf
   - number of leaves from a bud
   - smoothness of branch, suppleness of branch
   - color of leaves
   - number of veins
   - pattern of venation
   - number of leaves on a branch.
3. Discuss observations. Ask if there are any patterns.
4. Ask students if they have any ideas (inferences) about why the differences might exist. Ask students why it is important to recognize patterns and make inferences. This might be a good opportunity to bring in a local plant specialist to answer questions and discuss possible causes for patterns students are observing. If none is available, there are many Web sites where they can connect with scientists.
5. Go to the GLOBE Web site and compare tree species they observed with those found in other latitudes. Are the same tree species found in other latitudes?
6. Ask students to list other possible variables (e.g. soil temperature, air temperature, day length, precipitation etc.) in the environment to monitor and make hypothesis as to why the observed changes have taken place. What variables affected the plants?

Assessment

GLOBE Science Log Entry

Have students write and/or draw in their learning logs about:

1. Why observation and classification are important skills in science. (Have students explain the terms observation and classification and describe several good examples of why observation and classification are important in science or daily life)
2. What patterns they observed during green-up or green-down at their site including variations among the same plant species and different plant species
3. What they might infer based on their observations about how plants at their site change with the seasons and possible causes for the variations

Use the following rubric to score the writing. Students who have difficulty writing can be interviewed for understanding.

Performance Task

Have students gather ten items other than leaves from outside and classify them in two different developmentally appropriate ways (teacher's discretion). For example, young students can put items in two groups, while older students might be expected to develop a dichotomous key. This has been presented in the Land Cover *Leaf Classification Learning Activity.*

Use the following rubric as you circulate throughout the class to score the performance task. Students who have difficulty writing can be interviewed for understanding.

Skills Checklist

Use the following checklist during the lesson to document students' skill abilities in the processes of science.

A First Look at Phenology
Skills of Science Assessment Checklist

Criteria	Student Names							
Observes carefully i.e.uses more than one sense *(Exploration, Step 1)*								
Correctly uses hand lens to gather information *(Exploration Steps 2, 3 and 4)*								
Identifies at least one pattern in plants *(Discussion, Question 2)*								
Records data *(written or drawing of observations of plants in GLOBE Science Notebook)*								
Infers reasonable causes for variations based on observations *(Discussion question 4)*								
Classifies in developmentally appropriate way *(dichotomous key, Venn diagrams, or grouping)*								

Assessment Rubric

A First Look at Phenology
Journal and Performance Rubric

	5	4	3	2	1
Discussion – Importance of observation and classification	Discussion shows thorough understanding of terms and several good examples of why they are important	Discussion shows thorough understanding of terms and their importance	Explanation in student's words show several ways of observation and classification and why they are important	Discussion shows understanding of the terms and some ability to discuss their importance	Discussion shows lack of understanding of terms, observation and/or classification
Discussion– Seasonal changes and possible causes	Includes thorough discussion of variations among and between plants related to seasonal change; Many inferences about causes	Includes thorough discussion of variations among and between plants related to seasonal change; Some inferences about cause	Includes thorough discussion of variations among and between plants related to seasonal change	Discussion shows some ability to apply variations observed to seasonal content	Little evidence of an understanding of how site observations are impacted by seasonal change
Discussion – Local patterns in senescence and but discussion shows of understanding	Thorough discussion of variations among and **green-up** inferences about causes for variations	Discussion of variations among and between plants; between plants; Many for variations	Discussion of variation between and among at Inferences about causes Some inference	Missing discussion of either variation among least 3 types of plants; No inference	Some details provided or between plants; lack of change over time
Performance Task – Constructs viable classification scheme(s) appropriate for developmental level	Constructs classification scheme correctly to classify 10 objects two different ways; No errors; Properties used show careful observation	Constructs classification scheme correctly to classify 10 objects two different ways; No more than one error; Properties used to show careful observation	Constructs classification scheme correctly to classify 10 objects two different ways; No more than one error; Properties used to show good observation	Some errors in construction of classification scheme to classify 10 objects; Properties used show lack of careful observation	Many errors in construction of classification scheme to classify 10 objects; Properties used show lack of careful observation
Performance Task – Classifies a set of teacher selected items, appropriate for developmental level	Correctly uses dichotomous key (or grouping for younger students) with no errors	Correctly uses dichotomous key (or grouping for younger students) with no more than one error	Correctly uses dichotomous key (or grouping for younger students) with two errors	Correctly uses dichotomous key (or grouping for younger students) with 3-4 errors	Correctly uses dichotomous key (or grouping for younger students) with many errors

P4: A Beginning Look at Photosynthesis: Plants Need Light

Purpose

To develop an understanding of plants' response to light

Overview

Students will do simple investigations to observe plant responses to light.

Student Outcomes

Students demonstrate their understanding that the same plant species may show observable differences under different light conditions (i.e. kinds of light or duration of exposure). Students demonstrate their ability to set up and conduct a simple investigation, and to use process skills.

Science Concepts

Life Sciences

- Organisms' functions relate to their environment.
- Plants and animals have life cycles.
- All organisms must be able to obtain and use resources while living in a constantly changing environment.

Scientific Inquiry Abilities

- Observing
- Inferring
- Predicting
- Collecting data
- Analyzing data
- Setting up and carrying out a simple investigation
- Design and develop scientific investigations.
- Use appropriate tools and techniques.
- Develop explanations and predictions using evidence.
- Use appropriate mathematics to analyze data.

Time

Two full class periods and a number of short sessions over the next two to three weeks to check branches and record observations

Level

Primary and Middle

Materials and Tools

- Small brown paper bags
- Brown paper bags
- Colored cellophane
- Various plants with leaves (inside and/or outside)
- Various light sources (incandescent, cool and warm fluorescent, full spectrum, sun, etc.)
- Rulers
- GLOBE Science Log with two columns, one for narrative description and one for pictorial/graphic

Preparation

Collect a variety of plants. Plants need to be large enough for students to cover three branches of one plant or you will need three replicate plants of each type/species.

Prerequisites

None

Background

Photosynthesis is the process by which plants, algae and some bacteria use light energy to produce food (sugars) out of carbon dioxide and water. *Chlorophyll,* a pigment which gives plants their green color, traps light energy for these organisms to use in making food. Photosynthetic organisms are *producers* that provide food to nearly all *consumers* on Earth. For most living organisms, photosynthesis is the first step in the food chain which connects living things. Every land animal depends to some degree on green plants. Photosynthesizing plants take carbon dioxide from the air, water from the soil, and use energy from the sun. Some of the light energy as it interacts with chlorophyll, is used to split water molecules into hydrogen and oxygen. Light energy is then used to join hydrogen and carbon dioxide together to form a new molecule: sugar. The sugar formed is glucose, the food a plant uses for growth and maintenance. The process of photosynthesis is illustrated in the equation at the bottom of the page.

Sugars that plants make out of carbon dioxide and water are their only source of food that can be used immediately for energy, to make cell materials, or stored for later use. Water and minerals such as nitrogen and phosphorus dissolved in it (which may come from soil) are not sources of energy for plants or animals; therefore these are not considered plant food even though they are required for growth and survival.

What to Do and How to Do It

Getting Ready

1. Ask and discuss the following questions:
   - What do you think would happen if I put my favorite classroom plant in the closet for the rest of the year? Why do you think that might be?
   - What do you think plants need to live?
   - Have you heard the word photosynthesis?
   - What do you know about it? (Do not go into detail at this point, however.)
   - Do you think plants can grow with any kind of light?
   - Ask students what they think would happen if trees outside were covered and had no light. Ask what could cause this (lack of light and trees being covered) to happen.
   - Why do you think plant survival is important? (Be sure students understand that because of the food chain, all animals rely on plants for survival.)
2. Tell students they are going to set up a test to see what happens when part of a plant or a whole plant does not get light.

Exploration

Note: Beginning students will most likely need to do this as a group. Intermediate students can work independently in small groups using the following Work Sheet.

1. If appropriate for your students, discuss what *variables* (things that can change the result of the investigation) need to be

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} + \text{light energy} \xrightarrow[\text{chlorophyll}]{} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

controlled (or kept constant) to make this investigation a *fair test* of the need for light without having other factors come into play. Help students to understand that, as much as possible, everything needs to be kept the same except for the one thing that they will be changing, the kind or the duration of light.

2. Have each group decide what aspect of light they want to test (kind of light source, duration of exposure to light, distance from light source, etc.). Have each group give a prediction of what they think might happen depending on the variable they chose to test.
3. Have groups set up their investigation. Be sure to allow for replication by having students use more than one plant of the same species or more than one plant part per variable being tested. If necessary, discuss with each group how they are controlling all variables except the selected one. For example, if they chose to test the type or kind of light source, is the distance of the light source and the duration of exposure time the same for all the plants?
4. Have each group of students select three plants of the same species or three branches on one plant for the variable they are testing, and another set of three plants/branches for the control or, if possible, set up a *control* for the entire class. Students may use whole plants or plant parts, depending on the size and availability.
5. Decide as a group how often plants will be checked (observed) and data gathered. For intermediate students, discuss with each group what they think are ways of observing quantitatively or collecting quantitative data (Will they do any measurements, i.e. length or width of leaves, height of plant, count number of healthy looking or sick looking leaves etc.?)
6. Have students check plants carefully on a regular basis and write and draw their observations (what is happening), inferences ("why do you suppose it happened" idea), and predictions ("what is going to happen next" idea), in their science logs. Take a minute regularly to have students share and discuss these observations, inferences, and predictions. Be sure they understand that an observation is detected by one or more of their five senses, whereas an inference is a guess at what might have caused the effect they are observing. This is worth reviewing regularly, so students have a clear picture that observation and inference are two very different skills that are important in science. Prediction is a guess at what might happen given a scenario or set of circumstances. It may help to make three columns on a chart labeled *Observation, Inference,* and *Prediction* and put each observation in the correct columns. If students give you an inference when they should have observed, ask for the evidence that led them to their inference. For older students, you may want to require that they do quantitative observations or collect quantitative data. See step 5.

Discussion Questions/Generalize

Ask each group to report the results of the investigation on their plant(s). Discuss conclusions as a group. Ask students why they think they got the results that they did. If they say that plants need light to live or be healthy, ask them why they think that is. For what do they think the plant needs light? For younger students, don't worry about a thorough explanation of photosynthesis at this time if students don't already have a grasp of the concept. It is sufficient that they understand that plants need food, and that plants use sunlight to help make food (in the form of sugar) in a process called *photosynthesis.* For older students, it might be appropriate to discuss photosynthesis at this time (See background) and include information they have read on similar investigations done by other workers.

Assessment

Science Log Entry

Have students write and draw in their GLOBE Science Logs their ideas about:

- Why observation and inference is important in science and how they used these skills in their test or investigation
- Why it is important to cover their three test branches of plants with the same bags, water plants the same, and fertilize them the same
- How plants respond to various light conditions and why

Use the following rubric to score the writing. Primary students who have difficulty writing can be interviewed for understanding.

Skills Checklist

Use the checklist during the lesson to document students' skill abilities.

Performance Task

Have students observe a plant or plant part from your local environment. Tell them to use the most possible number of senses except taste. Students should be able to use four of their five senses (sight, touch, hearing, smell). Record their observations (qualitative and/or quantitative).

Have students infer some reasonable explanations why several leaves on the same plant are different.

Use the following rubric to score the writing. Primary students who have difficulty writing can be interviewed for understanding.

A Beginning Look at Photosynthesis
Skills of Science Assessment Checklist

Criteria	Student Names							
Identifies and controls variables								
Sets up investigation (including replication)								
Observes carefully using four senses, qualitative observations								
Measures accurately, quantitative observations								
Records data (observations of plants)								
Infers reasonable causes for results								

Assessment Rubric

A Beginning Look at Photosynthesis Journal and Performance Rubric

	5	4	3	2	1
Discussion – Importance of observation and inference	Discussion shows thorough understanding of terms and several good examples of why they are important	Explanation in student's words of several ways observation and inference are important and example of importance	Explanation in student's words of several ways observation and inference are important	Discussion shows understanding of the terms and some ability to discuss their importance	Discussion shows lack of understanding of terms, observation and/or inference
Discussion– Importance of controlling variables and the need for replication or repeated tests in investigations	Understands variables and the need to control them and need for replication; Well explained generalizations beyond this investigation	Understands variables and the need to control them and need for replication; Some ability to generalize beyond this investigation	Understands variables and the need to control them and need for replication	Understands variables but not the need to control them nor the need for replication	Some details provided but discussion shows lack of understanding of variables and the need to control them
Discussion – How plants might respond to light and whys	Discussion shows thorough understanding of how plants respond to light and why; Includes examples other than from investigation	Discussion shows thorough understanding of how plants respond to light and why; Includes example other than from investigation	Discussion shows good ability to generalize investigation results to how plants respond to light and why	Discussion shows some ability to generalize investigation results to plant response to light and possible causes	Little evidence of an understanding of how plants respond to light and why
Performance Task – Uses observation skills to gather data about local environment	States a number of quantitative and qualitative observations using more than three senses; No inferences included	States a number of quantitative and qualitative observations using at least three senses; No inferences included	States a number of quantitative and qualitative observations; No inferences included	States a number of observations but they do not reflect in depth effort; No quantification present; No inferences included	States observations that are few and superficial. No quantification present; No inferences included
Performance Task – Uses inference to propose causes for what he/she has observed	In depth discussion of at three reasonable inferences; Ability to generate reasonable generalization based on inferences beyond local environment	In depth discussion of three reasonable inferences; Supporting sentences	At least three inferences that are reasonable and developmentally appropriate; Inferences may be just one sentence	At least one reasonable inference that is reasonable and developmentally appropriate	Inferences are mostly incorrect

P5: Investigating Leaf Pigments

Purpose

To explore what pigments exist in leaves and their importance

Overview

Working individually or in groups, students will conduct an experiment using paper chroma-tography to separate pigments present in leaves.

Student Outcomes

Students will learn stated key concepts and be able to apply process skills in understanding chromatography and understanding that pigments other than chlorophyll are present in leaves.

Science Concepts

Physical Sciences

Chemical reactions take place in every part of the environment.

Life Sciences

Energy flows through the ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers).

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Observing and inferring

Hypothesizing and predicting

Collecting data

Analyzing and interpreting results

Communicating results and conclusions

Design and develop scientific investigations.

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Use appropriate mathematics to analyze data.

Communicate results and explanations.

Time

One class period for gear up and to set up experiment

One more class period for observations

Level

Middle, Secondary

Materials and Tools

White coffee paper filters, paper towels, filter paper or chromatography paper cut to 2 cm wide by 15 cm long

Non-Crayola brand felt-tipped pens with black, water soluble ink

Glass (baby food/juice jars) or plastic containers (8-10 oz. cups)

Water at room temperature

Hot water from faucet

Rubbing alcohol (70% isopropyl alcohol or 99% isopropyl alcohol)

Pencils, popsicle sticks, or drinking straws

Scissors

Ruler

Tape

Green leaves

Leaves that have changed color from green

Covers for jars, aluminum foil, or plastic wrap

Shallow pan or tray

GLOBE Science Log

Hand lens (optional)

Mortar and pestle for grinding leaves (optional)

Preparation

None

Prerequisites

ADULT SUPERVISION IS REQUIRED when using isopropyl alcohol. Please read all instructions completely before starting.

Observe all safety precautions.

Background

Chromatography is one of the procedures commonly used in many fields of science and industry to separate and identify substances within a mixture. A *chromatogram* is the separation pattern produced by each different mixture. The mixture is placed onto a medium such as paper or chalk, which absorbs water, alcohol or other solvents. As water or alcohol moves up by *capillary action* on the paper, molecules or substances dissolved in the mixture will travel at different speeds. The water or other solvent moves up the paper because capillary action is stronger than gravity and capillary action depends on *cohesion* and *adhesion*. Cohesion is the mutual attraction of water molecules and adhesion is the attraction of water molecules to other kinds of molecules, in this case paper. Various colors will appear at certain distances from their starting point because molecules of these colors have different sizes, shapes and solubilities. Molecules that dissolve better in the solvent will move along the paper more easily and quickly and will travel the greatest distance. Other molecules are not able to move as quickly and are left behind. By using paper chromatography, the different colors that make up black ink, and pigments in leaves can be separated and made visible.

Pigments are colorful compounds that absorb light. Pigment structure and amount determine variations in color. The pigment chlorophyll in leaves helps make photosynthesis happen by absorbing from sunlight the energy needed for putting together carbon dioxide and water to form glucose or food. Chlorophyll gives plants their green color and may hide the other pigments present in leaves. Chlorophyll absorbs all colors of visible light except green, which it reflects to be detected by our eyes. If all colors or wavelengths of visible light are absorbed and none are reflected, the pigment appears black to our eyes. Conversely, if all wavelengths are reflected, the pigment appears white to our eyes.

In autumn, changes occur in deciduous plant leaves before they finally fall from the branch. Chlorophyll breaks down and leaves change color when water and sap stop flowing into the leaves. As the green fades, orange color from the pigment *carotene*, and yellow color from the pigment *xanthophyll* appear. These pigments are also found in foods like carrots, bananas and egg yolks. Carotene and xanthophyll are secondary pigments that support the photosynthetic process by passing their absorbed light energy to chlorophyll. Further chemical changes in the leaves stimulate production of *anthocyanin* pigments giving bright red and purple colors. These are also commonly found in plants such as beets, red apples, and purple grapes, and flowers like violets and hyacinths. In the leaves, these pigments are formed in the autumn from trapped glucose. Different mixtures of chlorophyll and other pigments in the leaf give a wide range of autumn colors. Brown colors come from *tannin*, a bitter waste product. It is important to remember that the key photosynthetic pigment is chlorophyll because the light energy it absorbs is directly used for photosynthesis while the other pigments have to pass the light energy they absorbed, to chlorophyll.

The following explorations can be conducted by individual students or teams of students.

What To Do And How To Do It

Getting Ready

1. Write some words with a black (water soluble, non-Crayola) felt tipped pen on a piece of white paper. Ask students to make observations. How many colors do they see?
2. Ask students if they know what pigments are and what they do.
3. Ask students if they think there may be other colors hidden in the black ink and why they think so. If they seem at a loss for an answer, you could ask what colors do they think they need to make the ink in the black pen. Have they ever tried mixing different colors of paint? What did they observe? Discuss.
4. Ask students how they think they can find out if pigments other than black exist in the black ink.
5. Ask students what they think would happen if a dot of black ink were placed on a strip of coffee filter paper or paper towel and then the tip of the strip was placed in water?

Exploration 1

Introductory Learning Activity for Middle/ Secondary School Students

(This activity may also be used for Primary School students)

Separation of Colors in Black Ink

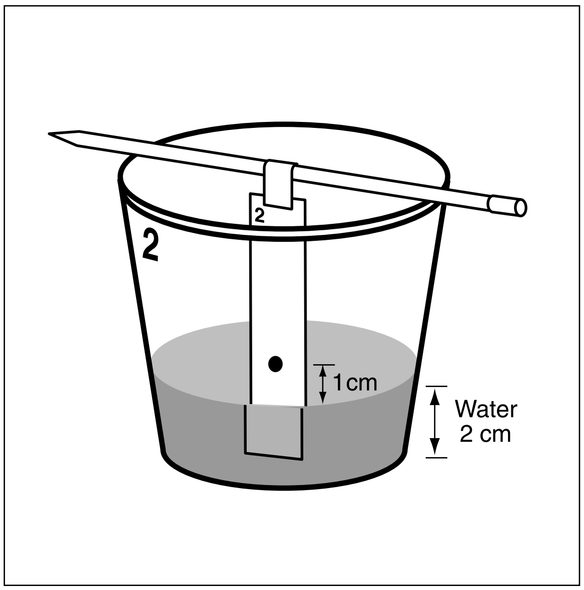
Have the students do the following steps or if you are trying to save some time, you may want to do steps 1-4 ahead for the students and use only one type of pen with water soluble black ink.

1. Cut several coffee filters into strips (2 cm wide by 15 cm long), one strip per pen.
2. Tape a number to each pen.
3. Using one of the test pens, place a dot of ink near the bottom (about $1^1/_2$ cm- 2 cm from the end) of each strip. Use a pencil to label the test strips at the top, with the number of the pen used to make a dot.
4. Put water (about 2 cm depth) in a glass or plastic container also labeled with the number of pen used to make ink dot. See Figure EA-P5-1.
5. Tape the end of the strip to a pencil or popsicle stick. Adjust the length of the filter paper by rotating the pencil so that the ink dot is 1 cm above the water level when the paper strip is put in the water by laying the pencil/stick across the top of each container. (If the ink dot is put below the water level, the ink will leach into the water instead of traveling up the strip)
6. Allow the water to travel about three quarters of the way up the strip and watch what happens to the ink dot.
7. If the ink you are using does not spread out, with adult supervision, re-test using rubbing alcohol instead of water as the solvent.
8. Repeat this process for each strip marked with a different pen and compare your results.
9. Let the strips dry and tape them to a sheet of paper as a record of different pen types.
10. Examine the strips with a hand lens. Measure how far the color(s) have travelled from the ink dot (for older students).

Generalize

- Ask students for their observations.
- Ask students for ideas about why other colors were not visible initially. Ask them for ideas about what might be happening (Why did some colors travel higher up the strip while others didn't? What do the results tell them about the makeup of the ink in the pen/pens?)
- If different pens are used, ask them what the similarities or differences in color patterns produced from different pens are and why they think this might be.
- Why it is that when all the colors are combined as in the pen or marker ink, it appeared black to our eyes? (Do not include this question if you think it is inappropriate for the grade level.)

Figure EA-P5-1: Paper Chromatography Setup



Formative Assessment for Introductory Exploration.

Science Log Entry

Have students write and draw about:

- Their observations (What happened to the ink dot when water traveled up the paper strips?).
- Why they think what they observed occurred (why some colors traveled higher up the strip while others didn't).
- How the patterns of color separation are different on strips marked with different pens and why this might be.
- Why it is that when all the colors are combined as in the pen or marker ink, it appeared black to our eyes. (Do not include this question if you think it is inappropriate for the grade level)

Skills of Science Checklist

Use the checklist during the lesson to document students' skill abilities in the processes of science.

Getting Ready for Color/Pigment Separation in Leaves

1. Ask students why they think leaves are green. (See if they come up with the idea of chlorophyll and how it absorbs all colors or wavelengths of visible light except green which it reflects)
2. Ask students what they think autumn leaves and ripening bananas might have in common.
3. Ask students whether they think other pigments besides chlorophyll exist in leaves. Why do they think so? How can they demonstrate this?

Exploration 2

Separate Colors in Green Leaves Using Chromatography

Green leaves may be collected from vegetation that dramatically changes color during senescence. For example, sugar maple leaves turn brilliant yellow in the autumn while white oak leaves turn dull brown. Thus sugar maple leaves would be a better choice than white oak for the experiment. And birch leaves would be better than alder leaves. However, students may not know which leaves change color dramatically in the fall. They may learn just as much if they choose green leaves from any vegetation. Have student teams do the following steps.

1. Collect 2-3 large fresh green leaves. Note location of plant and if you know it, also the plant genus.
2. Tear or cut up the green leaves into as small as possible pieces. Place the leaf fragments in a glass or plastic container.
3. Label the container with a number or name of leaf if known and location of the plant.
4. Add enough rubbing alcohol to cover the leaf fragments. Using a plastic spoon, carefully but vigorously stir the leaves in the alcohol (leaves can also be ground with a mortar and pestle if available). **Safety Note:** Isopropyl rubbing alcohol can be harmful if mishandled or misused. Read and carefully follow all warnings on the alcohol bottle. Supervise students closely.
5. Cover the container very loosely with lids or plastic wrap or aluminum foil. Place the containers carefully into a shallow tray containing 1 inch of hot tap water. **Safety Note:** Hot water above 66° C can quickly cause severe burns.
6. Keep the jars/containers in the tray of water for at least a half-hour, longer if needed, until the alcohol has become colored (the darker the better). Twirl each jar gently about every five minutes. Replace the hot water in the water tray if it cools off. Covered containers or jars may be kept overnight and contents used for chromatography afterwards.
7. Cut a long thin strip (2 cm wide by 15 cm) of coffee filter paper or chromatography paper for each of the containers and label it with a leaf name or code.

8. Remove containers from the water tray and uncover. Tape a strip of filter paper or chromatography paper to a pencil. Lay the pencil across the top of each glass/ plastic container. Adjust the length of the filter paper by rotating the pencil so that the end of the paper strip just touches the alcohol. The alcohol will travel up the paper, bringing the colors with it.
9. After 30-90 minutes (or longer) or after alcohol has traveled three quarters of the way up the strip, the colors will travel different distances up the paper. Different shades of green, and possibly some yellow, orange or red, depending on the type of leaf, may be seen on the chromatogram. Remove the paper strip and put on top of a paper towel to dry, then tape to a piece of plain white paper.
10. Examine the strips with a hand lens. Measure the distance(s) that the color(s) has/have traveled up the strip of paper. Save for the paper strip to compare results from the next experiment (Exploration 3).

Generalize

1. Ask students to write and draw their observations, and to share and discuss their findings with the whole group.
2. Ask them what they think the reason is for the way some colors traveled higher up the strip while others didn't? (Molecules of colors with bigger size and more adhesion, would travel shorter distances than those which are smaller in size and less adhesion).
3. Ask students what they think can be inferred regarding what pigment molecules are represented on the strip? (The different pigment molecules present in the leaves are represented by the colors shown on the strip: green for the chlorophyll pigment, yellow for the xanthophyll, orange for carotene).
4. Ask students what can be inferred if green is the dominant color present on the strip (Chlorophyll is the main photosynthetic pigment which gives leaves the green color. Other pigments may dominate when chlorophyll levels decrease.)
5. Ask students what accessory photosynthetic pigments are. If they can't remember, ask them how they think leaves are similar to bananas and egg yolks? (They contain carotene and xanthophyll which give them the orange/ yellow color.) If appropriate for the grade level, ask them why some pigments are designated as accessory? (Chlorophyll is the key photosynthetic pigment because it directly transfers the light energy it absorbs for photosynthesis. Xanthophyll and carotene, examples of accessory pigments, must pass the energy they absorb from sunlight to chlorophyll and not directly to the photosynthetic pathway.)

Formative Assessment

Science Log Entry

Have students write and draw in their science logs about:

- What their observations are. (What happened when the alcohol/ground-up-leaves mixture traveled up the filter paper?)
- Why they think what they observed occurred.
- Ask students to infer what pigment molecules might be present in the leaves based on the colors on the strip.
- What accessory pigments in leaves are and why they think these pigments are important.

Skills of Science Assessment Checklist

During the lesson/exploration, use the checklist to document students' skill abilities in the processes of science.

Investigating Leaf Pigments
Skills of Science Assessment Checklist

Criteria	Student Names							
Correctly follows instructions and steps in procedure to set up experiment and gather information								
Observes carefully								
Records data and explanations for observations, experiments, in science log								
Identifies similarities and differences in patterns of color separation								
Infers reasonable causes for variations in data obtained								
Verbal communication of understandings during generalization discussions, and brainstorming								

Exploration 3

Separate Colors in Fall Leaves Using Chromatography

- Repeat steps 1 through 8 from Exploration 2, this time using leaves that have changed color.
- You may have to wait much longer in steps 4 and 7.
- Compare strips with those obtained from Exploration 2. Write and draw their observations and comparisons, share and discuss with the whole group.

Generalize

1. Ask students what they observed when the alcohol/ground-up-leaves mixture traveled up the filter paper. Have them compare the processed strips or chromatograms to those from Exploration 2. Ask students to write and draw their observations, similarities and differences with results from Exploration 2, share and discuss with the whole group.
2. Ask them what they think the reason is for the way some colors travelled higher up the strip while others didn't? (Larger, more adhesive molecules travel shorter distances than smaller, less adhesive molecules if solubilities are the same).
3. Ask students what they think can be inferred regarding what pigment molecules are represented on the strip? (The different pigment molecules present in the leaves are represented by the colors shown on the strip: green for the chlorophyll pigment, yellow for the xanthophyll, orange for carotene and bright red or purple for anthocyanins).
4. Ask them what can be inferred from the presence of the dominant color present on the strip. (Chlorophyll is the main photosynthetic pigment usually present in high quantities in green leaves. Other pigments may dominate when chlorophyll levels decrease.)
5. Ask them if they know what accessory photosynthetic pigments are. (Chlorophyll is a photosynthetic pigment. Xanthophyll and carotene are examples of accessory pigments designated as accessory because they cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass their absorbed energy to chlorophyll.

Formative Assessment

Science Log Entry

Have students write and draw their observations in their science logs about:

- Their observations. (What happened when the alcohol/ground-up-leaves mixture traveled up the filter paper?)
- Why they think what they observed occurred.
- Ask students to infer what pigment molecules might be present in the leaves based on the colors on the strip.
- What accessory pigments are and why they think these pigments are important .
- What the similarities and differences are in the patterns of color separation on strips with alcohol extracts of green leaves to strips with extracts from leaves that have changed color.

Skills of Science Assessment Checklist

During the lesson/exploration, use the checklist to document students' skill abilities in the processes of science.

Final Assessment

Science Log Entry

Have students: 1) discuss their understandings of chromatography and its importance, 2) discuss their understandings of pigments and their importance including their importance to leaves, and, 3) how their observations are similar or different from chromatography of green leaves extract with that from leaves that have turned color (non-green leaves)_

Performance Task

Have students conduct their own inquiry on materials not previously explored such as different color pens, mixtures of food color or cake décor color pastes, colored candies, and, different kinds of natural and non-toxic chemical dyes by predicting what will happen, performing chromatography, reporting their results and analysis.

Use the rubric below to score the final GLOBE Science Log entry and the performance task.

Criteria	Developing	Proficient	Exemplary
Discussion of chromatography and its importance	Discussion shows lack of thorough understanding of chromatography and its value	Discussion shows thorough understanding of chromatography and its importance	Discussion shows thorough understanding of chromatography and its importance and show ability to apply to new situations
Discussion of pigments and their importance (including to leaves)	Discussion shows lack of thorough understanding of pigments and their importance	Discussion shows thorough understanding of pigments and their importance in leaf photosynthesis	Discussion shows thorough understanding of pigments and their importance in leaf photosynthesis, and show ability to connect to plant chemistry in general

P6: Global Patterns in Green-Up and Green-Down

Purpose

To investigate the annual cycle of plant growth and decline using visualizations and graphs

Overview

Students will analyze visualizations and graphs that show the annual cycle of plant growth and decline. Students will explore patterns of annual change for the globe and each hemisphere in several regions that have different land cover and will match graphs that show annual green-up and green-down patterns with a specific land cover type. The activity begins with a class discussion and then students work in small groups and come together again to discuss their findings.

Student Outcomes

Ability to use visualizations to analyze patterns

Understanding relationships between visualizations and graphs

Ability to describe global, hemispheric, and regional patterns of land cover growth

Science Concepts

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Humans can change ecosystem balance.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Analyzing visualizations for important patterns in seasonal change

Solving a problem using data in a visualization

Comparing across multiple variables

Using evidence from graphs and visualizations to characterize ecosystems

Use appropriate tools and techniques.

- Develop explanations and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicate results and explanations.

Note: Similar skills for the local scale are taught in the GLOBE phenology protocols. The GLOBE training video *Remote Sensing* explains how scientists use remote sensing to determine land cover types.

Time

Two 45-minute class periods

Level

Middle, Secondary

Materials

- Overhead projector and transparencies (4) or color visualization pages
- Scissors for students to share
- *Work Sheet* (2 pages) and flip book sheet
- Wall map or atlas showing major topographic regions

Preparation

Make copies of the *Work Sheet*s for all of the student groups. Students can work in groups: recommended group size is 2-3.

Prerequisites

Experience working with visualizations. See Learning Activities *Learning to Use Visualizations: An Example with Elevation and Temperature* and *Draw Your Own Visualization*, or the GLOBE Visualization Web Server.

Ability to read an X-Y graph

Familiarity with land cover types

Background

Plants have adapted their growth patterns to the local environment. Climate features such as temperature and amount of rainfall influence plant growth and dormancy. In many parts of the world, changes in plants can be observed as trees lose their leaves or sprout new growth. When plants sprout new growth we call it green-up; when they lose their leaves it is called green-down.

Scientists study the seasonal cycles of plant growth to understand climate change. If climate conditions change, the length of plant growth cycles may differ from that observed in previous years. Vegetation vigor refers to the amount of growth that plants experience. The growing season is the period between spring growth (green-up) and fall decline (green-down). If global warming is occurring and affecting the Earth, scientists would expect to see earlier dates for spring green-up than in past years. Scientists study these changes using data from sensors on satellites that cover large regions of the Earth.

Global patterns in green-up and green-down follow the annual climate cycle. This means that just as summer in the Northern Hemisphere occurs during winter in the Southern Hemisphere, green-up happens in the North while green-down is happening in the South. The Northern Hemisphere experiences a more dramatic green-up and green-down than the Southern Hemisphere does. This trend also occurs with climate patterns; the Northern Hemisphere experiences much colder winters and hotter summers than the Southern Hemisphere does. The reason for this is that the Northern Hemisphere contains most of the land on Earth. Land is more easily heated and cooled than water.

Vegetation vigor can be examined at a local level by observing the changes in vegetation that occur seasonally. The *Phenology Protocols* explore this by tracking changes in plant growth. In order to understand changes in vigor at a global level, satellite data must be used. This activity uses visualizations of vegetation vigor data that were collected by a sensor carried by a satellite. This sensor is called the Advanced Very High Resolution Radiometer (AVHRR) and is operated by the National Oceanic and Atmospheric Agency (NOAA). The vegetation vigor data collected by this sensor shows how much sunlight is being absorbed by plants for photosynthesis in contrast to the amount that is being reflected.

Unfortunately, the AVHRR measurements of vegetation vigor are not precise: the resolution of the data is 1 square kilometer. It is important, then, for GLOBE students to help scientists understand how good the AVHRR measurements are by collecting local data using the *Phenology Protocols*.

Visualizations of vegetation vigor help scientists understand how vegetation in different regions responds to the seasonal changes in weather. (Visualizations are combined with numerical data, in the form of a graph, of the average values per month.) Comparing vigor visualizations with ones showing different land covers in different regions can help scientists understand how different regions respond to the seasons.

What To Do and How To Do It

This activity can take up to two class periods depending upon the amount of introduction given and the length of the class discussions.

Day 1:

Conduct a class discussion to orient students to the visualizations and conduct an initial analysis of the difference in vegetation vigor over a year and the relationship between land cover types and vegetation vigor.

Day 2:

Divide students into small groups to analyze data in order to classify regions based on the change in the vegetation vigor over the year and to answer the *Work Sheet* questions.

Facilitate a class discussion during which the groups of students present their results and discuss the evidence they found for their conclusions.

In preparation for the class discussion, obtain copies of the color visualizations shown in Figures EA-P6-2 and EA-P6-3. Color copies are included in the hard copy of the *Teacher's Guide*. Color copies for printing onto transparencies or paper, or for projecting, can be obtained at the GLOBE Web site.

Step 1. Class Discussion

This activity uses both visualizations of data and graphs of data. Each visualization is based on a map of the continents. The first visualization, printed in Figure EA-P6-1 a, shows categories of land cover expressed using the MUC (Modified UNESCO Classification) System . For simplicity, some MUC classes are combined. The MUC classes of shrubland and barren land are represented as one class. All graminoid with trees classes (tall, medium-tall, and short) are also one category, Graminoid with Trees. Another MUC class, tropical mainly evergreen, is simply distinguished by its location: Tropical Forest. Finally, the MUC class Temperate Broad-leaved Deciduous is simply called Mixed Forest.

Each class is shown in a different color: tropical forest (blue-green), cultivated land (orange), graminoid with trees (brown), graminoid (yellow), mixed forest (green), shrubland and barren land (tan), and tundra (gray). Students should be familiar with the plants that grow in these land cover types. For each land cover type, a corresponding value for vegetation vigor in January and July can be seen in Figures EA-P6-2a and EA-P6-2b, respectively.

Initiate the class discussion by characterizing your local land cover type and discussing the seasonal changes observed in your local vegetation. How do different plants react to seasonal changes? Do all plants respond only to shorter daylight and colder temperatures? Do some react to periods of dryness? Discuss the major climate cycles in your area.

Next, orient students to the visualizations shown in Figures EA-P6-1 and EA-P6-2 as described in detail below. Figures EA-P6-2a and EA-P6-2b illustrate the seasonal extremes of vegetation vigor by showing values during January and July. Figure EA-P6-1b shows a visualization of the difference in vegetation vigor between January and July to show the amount of seasonal change. Refer back to Figure EA-P6-1a to explain the observed seasonal variation by showing the type of land cover present in major regions.

Seasonal Extremes in January and July

1. Explain that the visualizations of vegetation vigor in Figure EA-P6-2 are drawn using shades of green so that higher numeric values (which correspond to more vegetation) are darker shades. Vegetation vigor values in this visualization range from less than 0.05 to greater than 0.68. In order to connect this number to concrete experience, ask students to suggest what types of land cover would be good to show extreme values of minimum and maximum vigor. Vegetation vigor for deserts is about 0.08 year round, and for a rainforest is about 0.50. Connect the vegetation vigor with land cover types using the visualization in Figure EA-P6-2a. High values of vigor are seen for the rain forests of South America (the "tropical forest" class colored blue-green). Low values are seen for the Saharan desert in Africa (a "shrubland and barren land" class colored tan).
2. Invite students to describe the major patterns that can be seen in the January and July visualizations of vegetation vigor. A wall map (for naming geographical regions) or atlas with a terrain feature map (for speculating on causes) can help.
   - In January most of the high values are found in the Southern Hemisphere, particularly in South America, Africa, and South Asia.
   - In July the mid-latitudes of the Northern Hemisphere show substantial vegetation vigor, especially in the eastern part of North America, Europe and Asia. During this same month vegetation vigor persists (though at a reduced level) in the Southern Hemisphere in South America, Africa, and South Asia in a pattern similar to that observed in January.
3. After looking at individual areas, invite students to compare the two months.
   - July shows a much higher total value because there is substantial vigor in both hemispheres.
   - You can quantify how much higher July is than January using the global mean values listed on the visualization. These mean values show approximately a fifty-percent rise: from 0.16 in January to 0.29 in July.
   - Ask students to speculate why the Northern Hemisphere's summer (July) is so much more productive globally than the Southern Hemisphere's summer (January). One important part of the answer is that the Northern Hemisphere experiences a sharper seasonal change than the Southern because most of the land on Earth is located in the North, and land is more easily heated and cooled than is water. However, another part of the answer lies in their distinctive land covers; some plants, such as trees in the rain forests of the Southern Hemisphere, stay green all year. Thus, the vigor of different land covers can change significantly during the year. Just how much they change can be seen using Figure EA-P6-1b, Seasonal Change: July minus January, as described below.

Visualizing Amount of Seasonal Change

In order to see the influence of climate on vegetation vigor, discuss the visualization in Figure EA-P6-1b that shows the result of subtracting vigor values in July from values in January. This visualization makes explicit how much change takes place and where it happens.

Figure EA-P6-1a: Land Cover Type

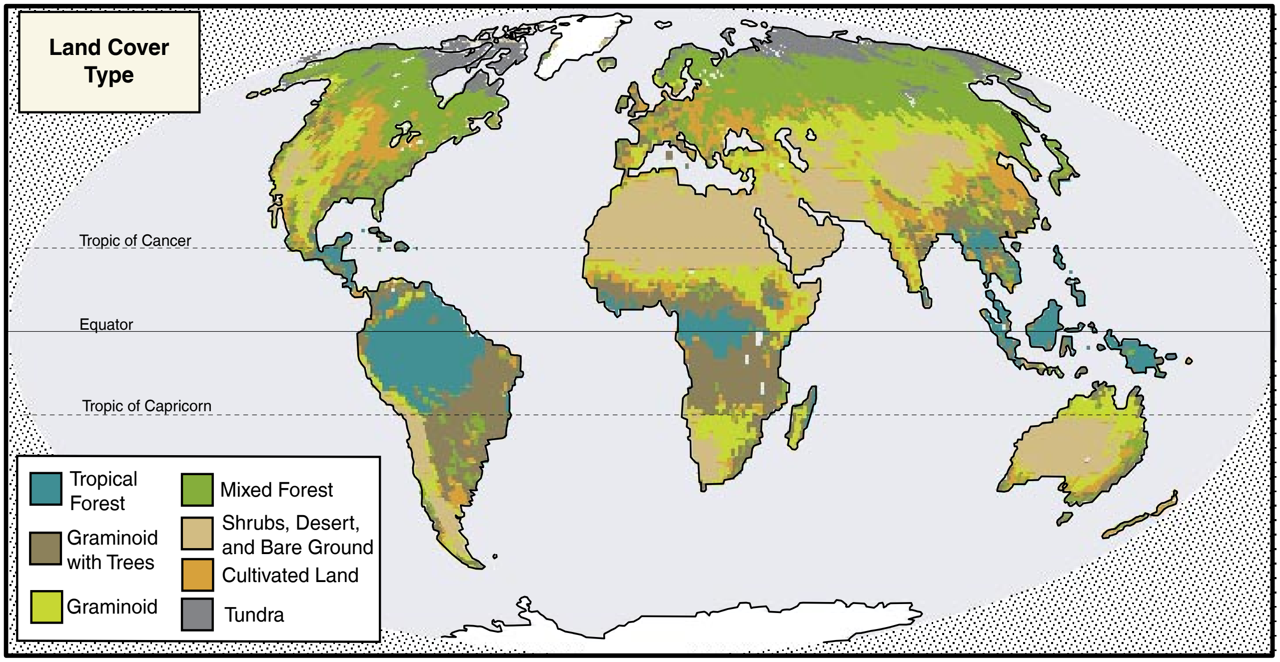


Figure EA-P6-1b: Seasonal Change: July Minus January

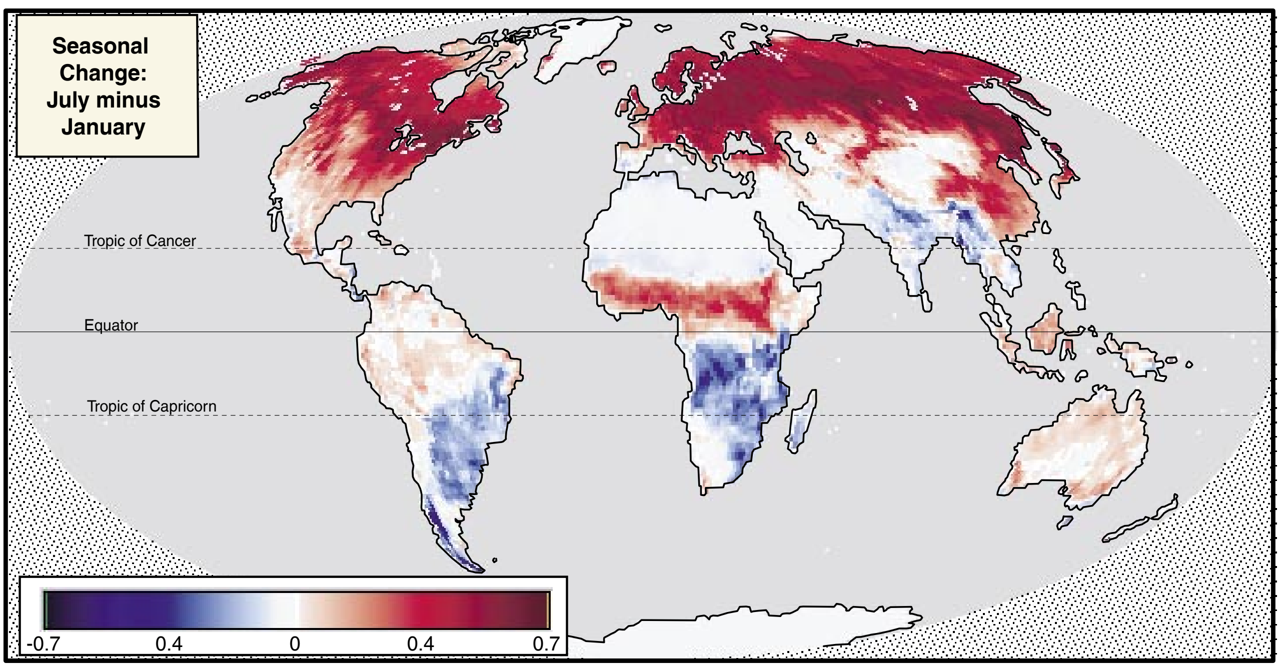
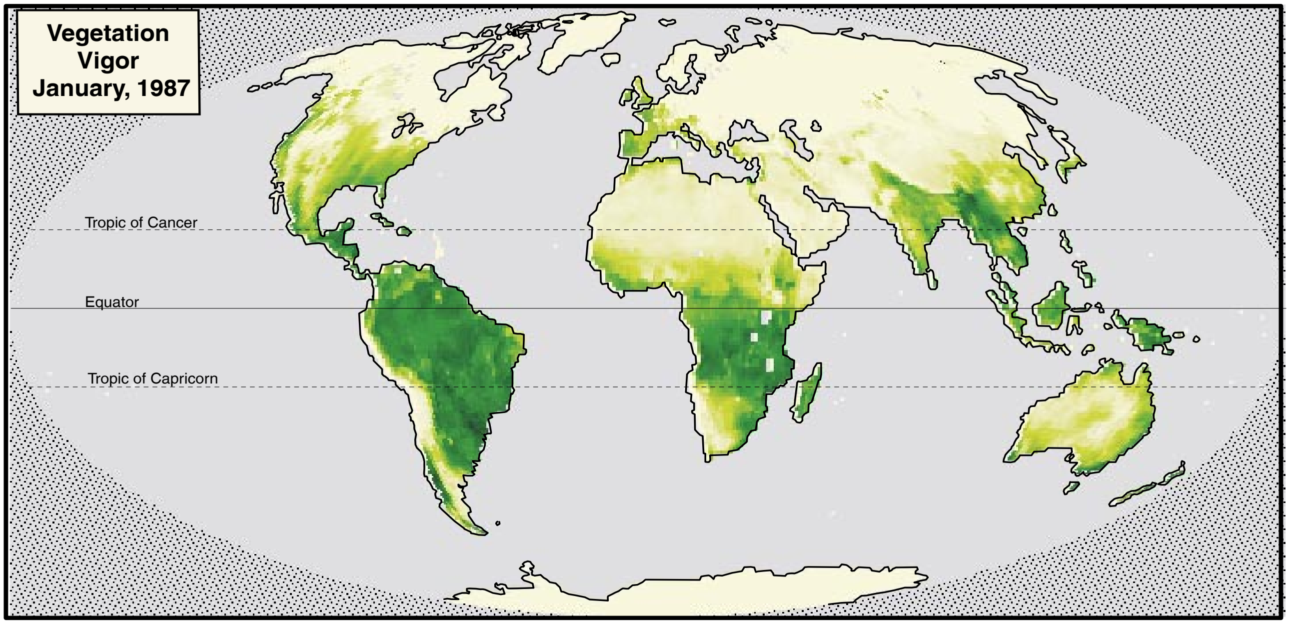


Figure EA-P6-2a: Vegetation Vigor, January, 1987



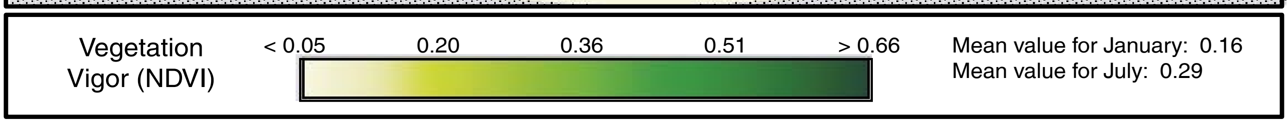
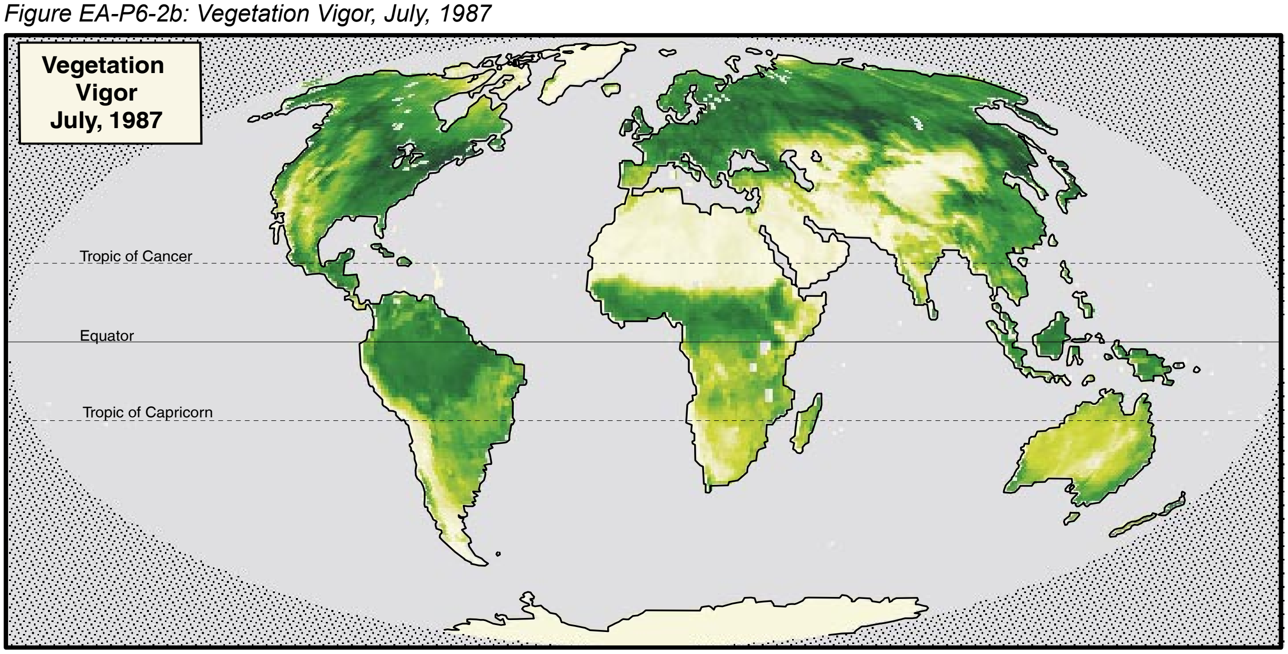


Figure EA-P6-2b: Vegetation Vigor, July, 1987



Step 2. Group Problem-Solving

The class discussion emphasizes global and hemispheric differences. In group problem-solving students will investigate vegetation vigor at a regional level of detail. They will characterize regions based on their annual pattern of vegetation vigor and thereby determine the predominant land cover for that region. Students will use an X-Y graph of monthly vegetation vigor and a visualization flip book that shows changes in vegetation vigor, by region, over a twelve-month period.

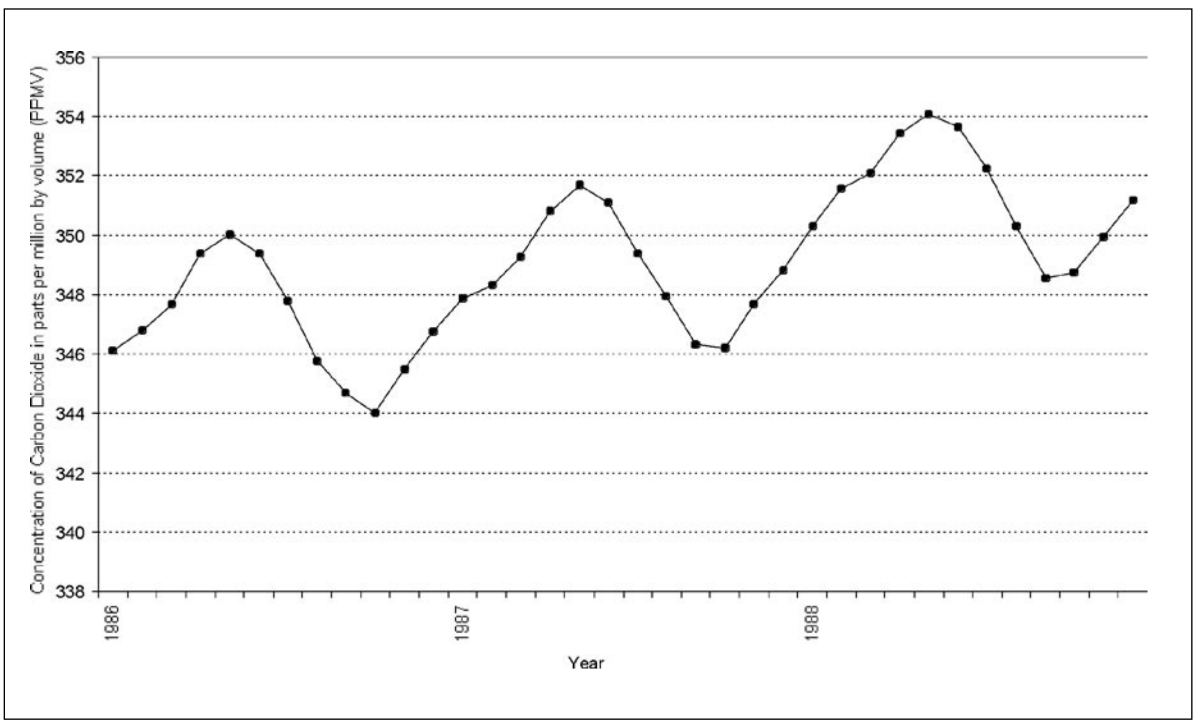
Hand out the *Work Sheets* to each group. Hand out the two flip book pages (one with even-numbered months, one with odd-numbered ones) to each student.

- Have each student cut out the monthly vegetation vigor visualizations from the two pages and assemble them into a flip book. (To reduce the number of copies needed, the activity can be completed using only one of the pages, showing every other month.)
- Students will use the vegetation vigor flip book to look at change over time in specific regions. The shades of gray in the flip book correspond to values on the graph. The students' task is to extract information from the graph and combine it with both the flip book information and land cover descriptions to determine which land cover type goes with which graph.
- The *Work Sheet* asks students to explain their choice. Ask students to be sure to use evidence from the flip book and land cover descriptions in their explanations.

Step 3. Group Presentations

Bring the students back together for a discussion of the results. Emphasize the important differences between the ecosystem dynamics of the regions, and suggest factors that might affect differences in vigor for different land covers. As students present their answers, watch for opportunities to hone their abilities to present ideas with sufficient justification. While students are characterizing regions, it is easy for them to focus only on finding the right answer (perhaps by using a process of elimination) and to not think about the reason they were able to determine the land cover type. When

Figure EA-P6-3: Atmospheric Carbon Dioxide Concentration, Mauna Loa Observatory, Hawaii



the students engage in discussion about their answers, they need to provide good evidence of why their answer is correct.

Further Investigations

The global occurrence of green-up and green-down causes an annual fluctuation in the amount of carbon in the atmosphere. This fluctuation occurs because vegetation—like all forms of life on Earth—is made partly of carbon. When plants grow, they take carbon dioxide out of the atmosphere. When plants decay, they release carbon dioxide into the atmosphere. If the amount of vegetation declines, less carbon dioxide is removed from the atmosphere. The graph in Figure EA-P6-3 shows atmospheric carbon dioxide per month for 3 years. Although the measurement is taken from only one location, it provides a global measure because of efficient mixing within the atmosphere. There are a number of interesting patterns to explore in this graph. Why is the decline so much faster than the rise? Why is the peak value of each succeeding year higher than that in the previous one?

Resources

You can analyze a large number of vegetation vigor visualizations using the GLOBE Visualization Server. The "Image Spreadsheet" option allows these visualizations to be further analyzed in relationship to other variables (e.g., temperature). The GLOBE Earth System poster provides an example of a spreadsheet of this sort in which vegetation vigor is contrasted with several other climatic variables. Finally, see the *Match the Biome* activity on the GLOBE Web Server (under News and Events). This activity asks students to connect climatic diagrams showing temperature and precipitation with land covers depicted in photographs.

Global Patterns in Green-Up and Green-Down

Work Sheet

Names: ____

Directions: Name the Land Cover

This activity will help you investigate vegetation vigor at a regional level. You will use an X-Y graph of monthly vegetation vigor and a visualization flip book that shows changes in vegetation vigor, by region, over a twelve-month period. From the graph, you will find the months in which each region has its growing season and how much the vegetation grows compared to other regions. You will then match the data from the X-Y graph to the vegetation vigor visualization in order to name the dominant land cover for that region.

1. Assemble the vegetation vigor flip book by cutting out each month and putting the pages in order from January to December. Using the Land Cover Locations map, look at how each region changes throughout the year. To begin, pick one region and one month, and use the flip book scale to determine the value of vigor in that month for that region. Repeat this for each region.

2. There are text descriptions of the land covers that you can use to understand how the vegetation changes in the map areas over one year.

3. Each line on the Vegetation Vigor graph represents one of the land cover locations. Your task is to name the land cover that each line corresponds to using data from the graph, the land cover descriptions, and the flip book. Use the following steps to do this.

Maximum and Minimum Vegetation Vigor: For each line on the graph, find the months in which the **maximum** and **minimum** values of vegetation vigor occur. Estimate the value of vigor in those months to the nearest 0.05. Record your results. You can get a clue to the answer using the flip book and its scale. For the maximum value you recorded, find that shade on the flip book scale and try to locate it in one of the regions.

Change: Another clue comes from the amount of change in the vigor over the year. Look at how much the line changes or stays level. Compute the value of the change in vigor by subtracting minimum vegetation vigor from the maximum value. Look again at the flip book. Which regions change a lot over the months? Which stay the same?

Growing Season: Knowing when a dramatic change occurs, such as green-up or green-down, can help you name the land cover. The graph shows the months of green-up and green-down: look for months in which the vegetation vigor value starts to increase from a low value (green-up) and decrease from a high value (green-down). Record the values you find for green-up and green-down.

Land Cover: Now you have enough clues to name the land cover. Be sure to explain your choice using evidence from the clues. Describe the clues from the graph, the flip book, and the land cover description.

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
○——○	Month: Value:	Month: Value:		
Land Cover:	**Explanation:**			

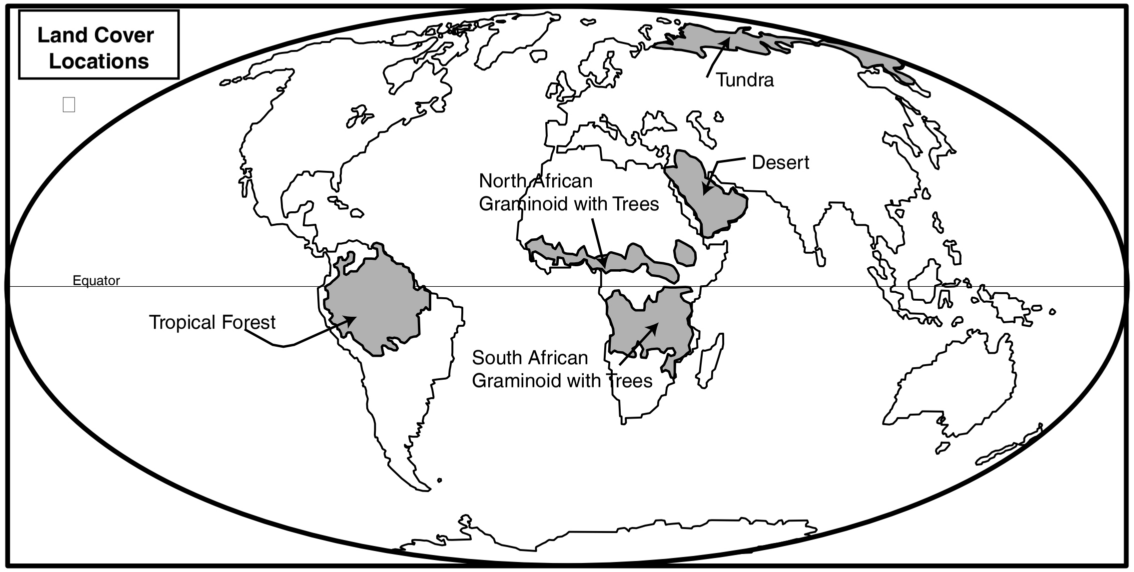
Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
□——□	Month: Value:	Month: Value:		
Land Cover:	**Explanation:**			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
▲——▲	Month: Value:	Month: Value:		
Land Cover:	**Explanation:**			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
△——△	Month: Value:	Month: Value:		
Land Cover:	**Explanation:**			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
●——●	Month: Value:	Month: Value:		
Land Cover:	**Explanation:**			

Global Green-Up and Green-Down Work Sheet



Flip Book Scale: Vegetation Vigor (NDVI) Value

0.05 | 0.36 | 0.66

Land Cover Descriptions

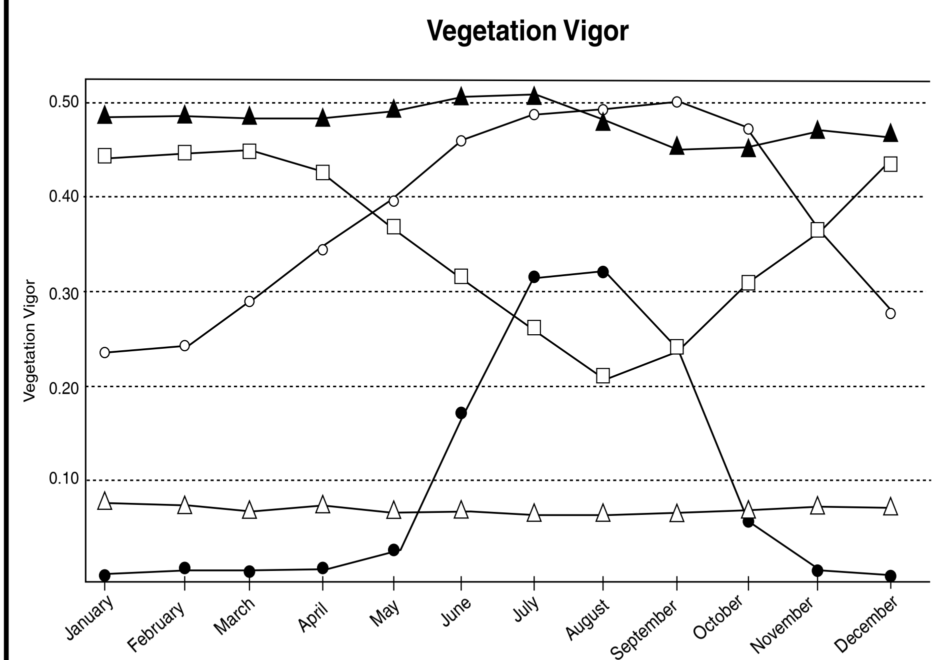
Tundra: High latitude treeless plains that occur in harsh climates of low rainfall and low average temperature.

Tropical Forest: Tropical latitude ecosystem dominated by broadleaf evergreen trees.

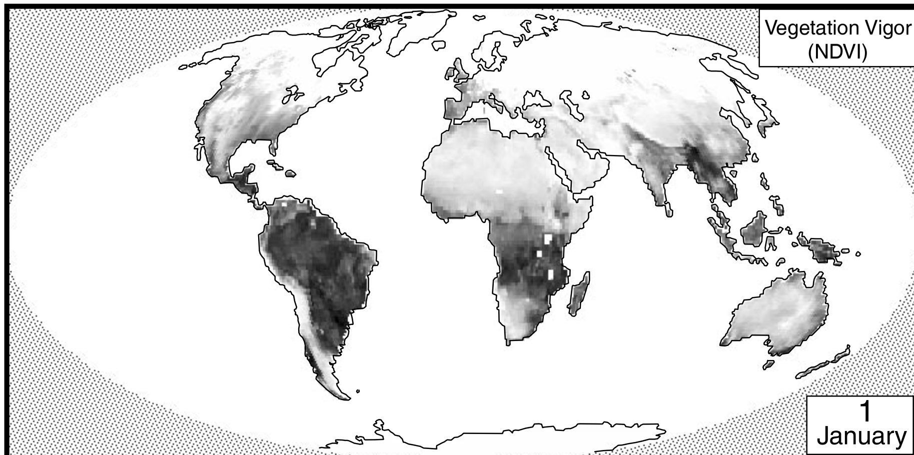
Desert: Ecology limited by extremely low annual rainfall and sparse, low vegetation.

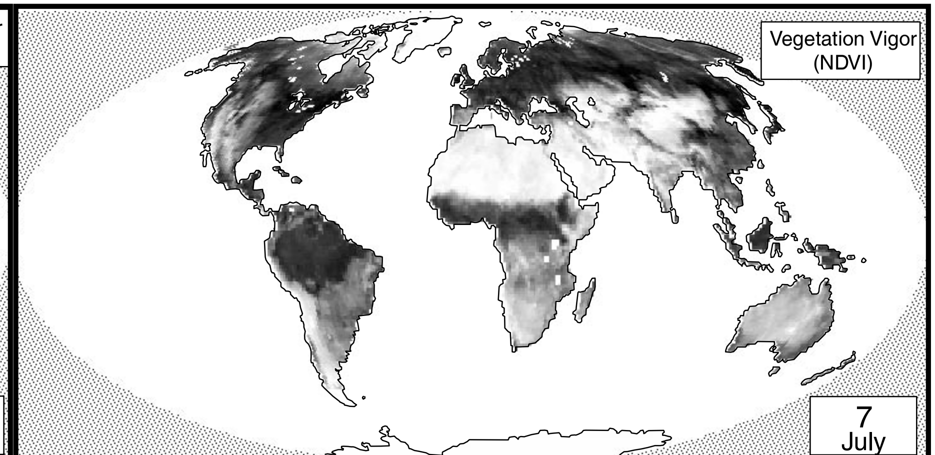
North African Graminoid with Trees: A moderately dry ecosystem dominated by grasslands and small trees.

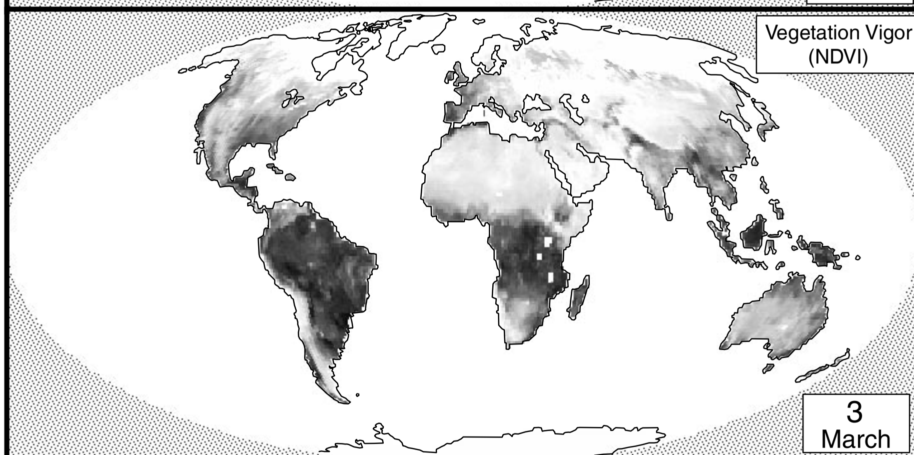
South African Graminoid with Trees: A moderately dry ecosystem dominated by grasslands and small trees.

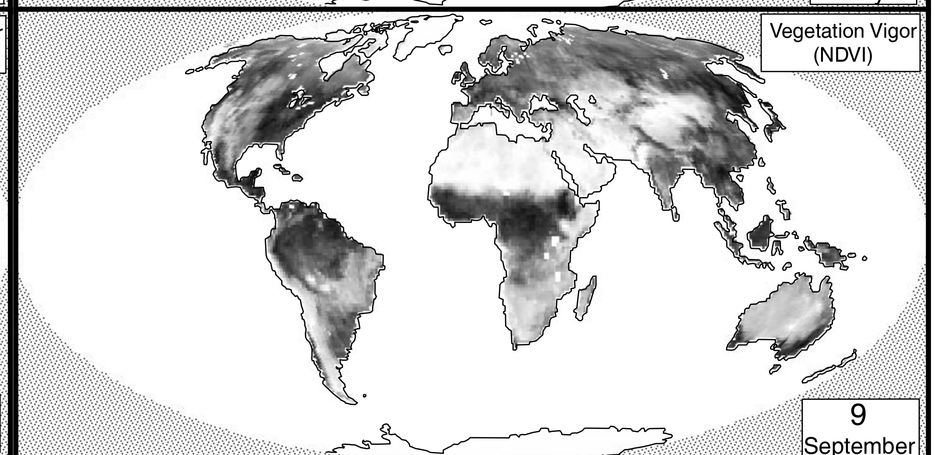


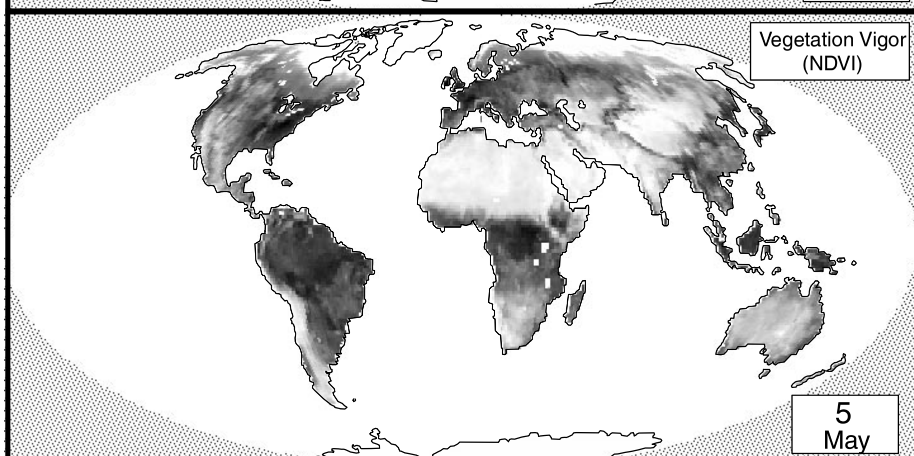
Work Sheet: Odd Months

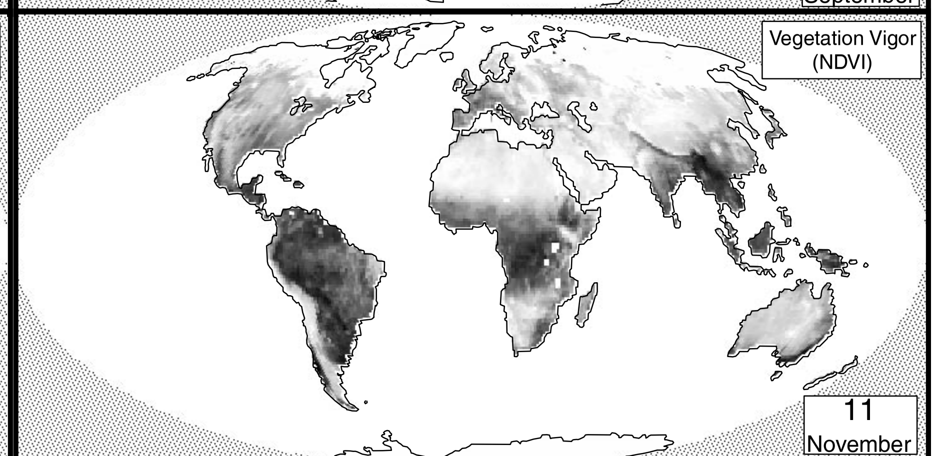




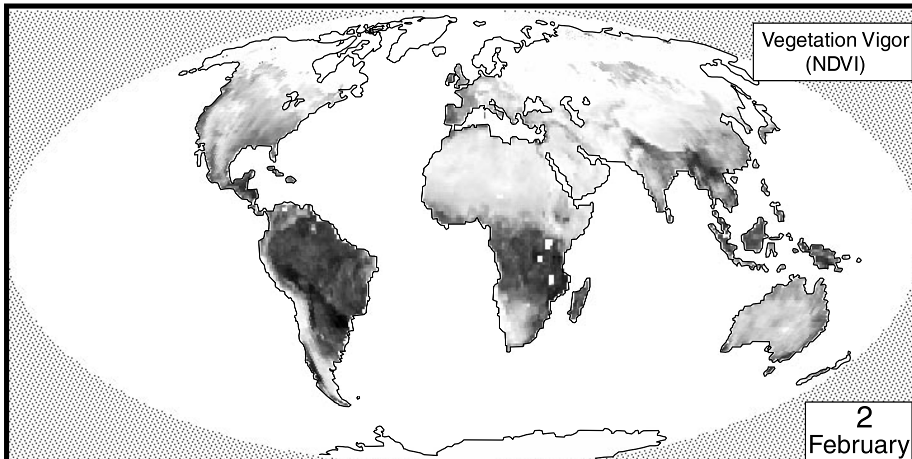


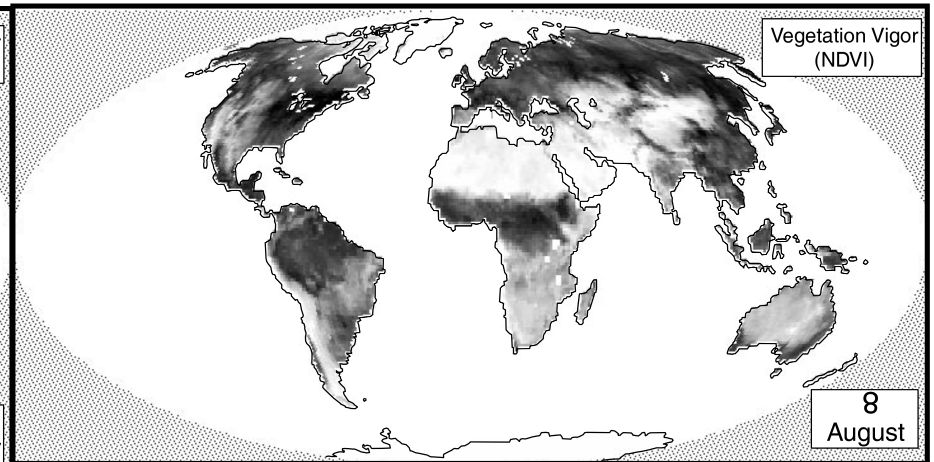


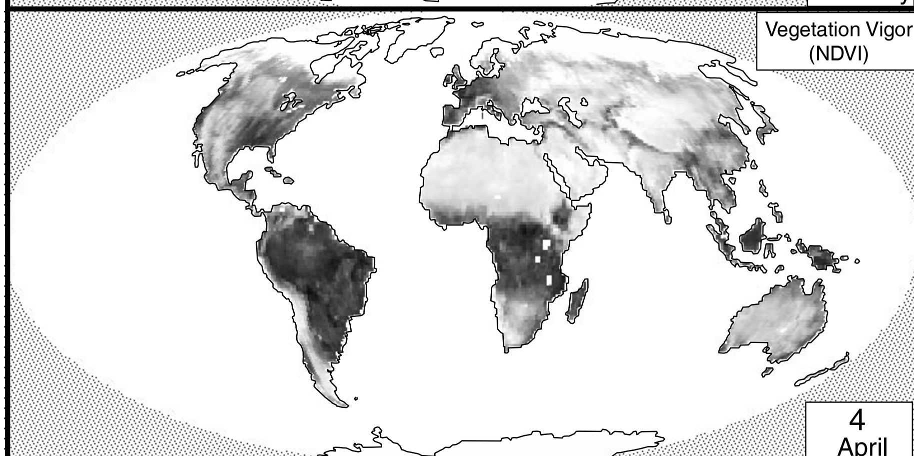


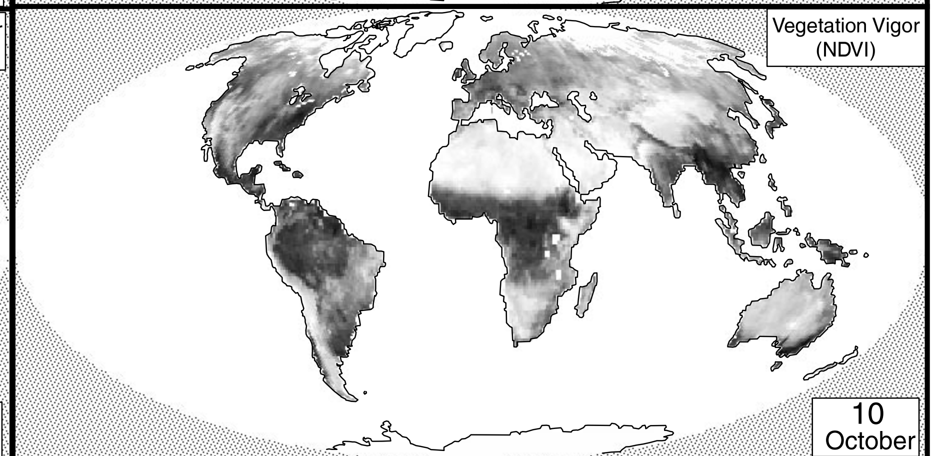


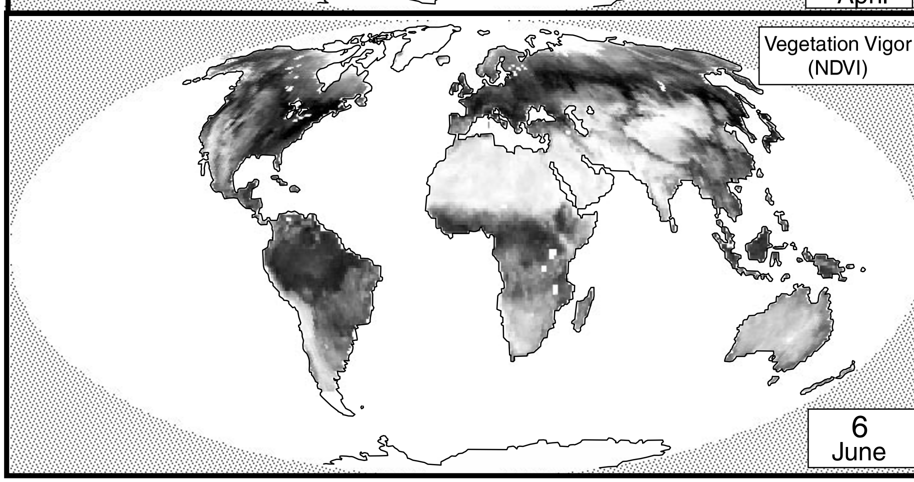
Work Sheet: Even Months

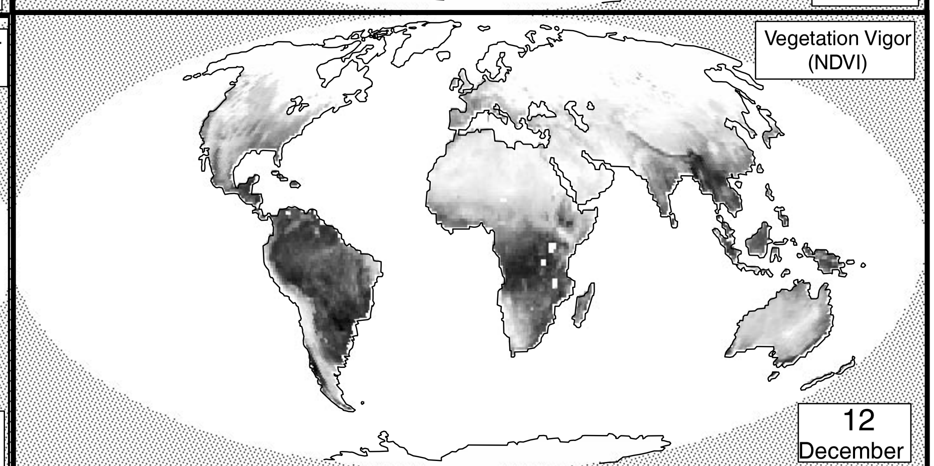












Global Patterns in Green-Up and Green-Down

Rubric

For each criterion, evaluate student work using the following score levels and standards.

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, but needs improvement

0 = Answer is blank, entirely arbitrary or inappropriate

1. Fill out the table with observations from the X-Y graph for maximum vegetation vigor, minimum vegetation vigor, change, and growing season.

Score Level	Description
3	The table is filled out with correct observations from the graph (see student example). For some, such as the darkened triangles (third row) and empty triangles (fourth row), there is little distinction between the maximum and minimum values, or, as with the darkened circles (bottom row) the minimum values are all similar. In these cases there is no one correct answer. A student may select one of these similar months for a low or a high, but the key point is that they identify a very small value for Change.
2	The table is completely filled out. Most of the values are correct. Student may not have rounded the numbers correctly.
1	Table is mainly filled out. Many of the values are correct or close to correct.
0	Table not filled out, too sloppy to read, or the majority of the values are arbitrary.

2. Complete the table with observations from the graph, table and flip book (score individually for each land cover assignment).

Score Level	Description
3	The land cover is correctly filled out and the explanation provides a complete evidence-based justification: it describes the line in the graph, references the land cover in the flip book, and makes a comparison to other land covers/lines or offers other explanations of why this is a sensible choice.
2	The land cover is correctly filled out but the explanation provides only partial justification of the choice or provides logical justification without evidence from the materials consulted. Alternatively, the chosen land cover is incorrect, but the explanation provides a reasonable justification for the selection.
1	The land cover is incorrectly filled out and the explanation is present but insufficient, offering minimal evidence or logical argument.
0	Land cover is not filled out, or is incorrect. Logical explanation is omitted.

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
○—○	Month: *September* Value: *0.50*	Month: *January* Value: *0.25*	*0.25*	*January to September*
Land Cover: *North African Graminoid with Trees*	Explanation: *This one is pretty much the opposite of the South African graminoid with trees, and it is the only one that gets as dark as the tropical forest in the flip book. It has its summer when North America has its summer, so it gets greenest in that hemisphere's summer (June-*			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
□—□	Month: *March* Value: *0.45*	Month: *August* Value: *0.20*	*0.25*	*September to March*
Land Cover: *South African Graminoid with Trees*	**Explanation:** *This is the only one with its peak is in the Southern Hemisphere's summer, so it has to be in the Southern Hemisphere. The flip book also shows this area as getting dark (high vegetation vigor) during January to March. It also stays pretty dark all year (compared to the desert). It is the opposite of the North African graminoid with trees line.*			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
▲—▲	Month: *July* Value: *0.50*	Month: *September* Value: *0.45*	*0.05*	*October to July*
Land Cover: *Tropical Forest*	**Explanation:** *This one has the highest overall values and it stays very high all year in the flip book and the graph. It is the highest (almost) all year in the graph. This makes sense since it is near the equator so it doesn't get summers or winters.*			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
△—△	Month: *January* Value: *0.05*	Month: *May* Value: *0.05*	*0.0*	*There isn't really one.*
Land Cover: *Desert*	**Explanation:** *This is the only one on the flip book that stays white all year long. This means that the values are really low all year, probably because there isn't very much vegetation to grow. It is really low on the graph too. It is probably higher than the tundra for part of the year because it does have something growing in the winter, while the tundra is ice.*			

Symbol	Maximum Vegetation Vigor	Minimum Vegetation Vigor	Change	Growing Season
●—●	Month: *August* Value: *0.30*	Month: *January, December* Value: *0.0*	*0.30*	*April to August*
Land Cover: *Tundra*	**Explanation:** *This line has the largest change of all the lines. It has no vegetation vigor until April (it is white in the flip book), then it gets very dark very quickly, then turns white again. This makes sense for it to be so far north, because the growing season there is very short. Its highest value never reaches as high as the tropical forest, and for the time that it is very high (July, August), it is darker in the flip book than the South African graminoid with trees.*			

P7: Limiting Factors in Ecosystems

Purpose

To understand that physical factors—temperature and precipitation—limit the growth of vegetative ecosystems

Overview

Students correlate graphs of vegetation vigor with those of temperature and precipitation data for four diverse ecosystems to determine which climatic factor is limiting growth. These ecosystems range from near-equatorial to polar, and span both hemispheres. The activity begins with a class discussion in which data from two of the ecosystems are analyzed and then students work in small groups to analyze two others. They then come together again to discuss their findings with the class.

Student Outcomes

Ability to use X-Y graph to analyze patterns in data

Understanding of relationships between visualizations and graphs

Ability to describe global limiting factors in ecosystem growth

Science Concepts

Physical Sciences

Sun is a major source of energy for changes on the Earth's surface.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

Seasons result from variations in solar insolation resulting from the tilt of the Earth's rotation axis.

The sun is the major source of energy at Earth's surface.

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Humans can change ecosystem balance.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Analyzing graphs to find patterns and to correlate variables

Using evidence to support conclusions

Discriminating among different factors that can affect ecosystem growth

Presenting material to a group

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

Two 45-minute class periods

Level

Middle, Secondary

Materials

Overhead projector and transparencies (4) or color visualization pages

Preparation

Make copies of the *Work Sheets* for all of the student groups.

Prerequisites

Experience working with visualizations. See Learning Activities, *Learning to Use Visualizations: An Example with Elevation and Temperature* and *Draw Your Own Visualization,* or the GLOBE Visualization Web Server.

Ability to read an X-Y graph

Familiarity with MUC land cover types

Background

The influence of the environment on plant growth can be readily seen in gardens and houseplants. Many plants grow best in fertile, well-drained soil, while others have evolved to grow in more extreme soil conditions. Some plants are shade tolerant; others thrive under lots of daily sunlight. Gardens and houseplants represent small-scale ecosystems that we can influence by changing the environment. One of the features of an ecosystem is that its growth is limited under normal conditions by competition for resources within the system and by external factors such as environmental changes. If the presence or absence of a factor limits the growth of the ecosystem elements, it is called a *limiting factor*. There are several fundamental factors that limit ecosystem growth, including temperature, precipitation, sunlight, soil configuration, and soil nutrients.

Two readily observed limiting factors are temperature and precipitation. Scientists can measure, on the scale of very large regions of land, how these factors shape the kinds of ecosystems that exist in those regions. Global satellite measurements of *vegetation vigor*, or the amount of plant growth, can be compared against other factors to understand how climate factors limit vegetation growth.

It is easiest to understand how environmental factors influence vegetation growth by looking at ecosystems in very different geographical regions. Near the northern polar region there is a flat, treeless zone of Dwarf-Shrubland land cover called *tundra*. ("Dwarf-shrubland" is the Level 1 Modified UNESCO Classification (MUC) term.) Tundra vegetation consists of low-growing shrubs, grasses, and mosses that can tolerate short growing seasons and permafrost. North of the Tropic of Cancer in the temperate zone there is a region characterized by conifers and broad-leaved trees. This area is the boreal (meaning cold temperate climate) zone of mainly Evergreen Forest (MUC 01). Elsewhere in the Northern Hemisphere temperate zone, we find grasslands containing grasses and grass-like plants, (MUC 41-43, Graminoid classification). Such grasslands also occur in the tropical zone and may grow with trees to form plant communities called *wooded grassland* or, in the MUC system, Graminoid with Trees.

Scientists are interested in the season when vegetation comes out of winter dormancy, grows, and reproduces, called the *growing season*. They are concerned, for example, that a lengthening of the growing season in the temperate and boreal zones could be an indication of global warming. In order to understand the growing season, scientists look at global changes in plant growth (green-up) and decline (green-down). Sensors on satellites can measure how much vegetation is covering parts of the Earth and scientists use this to determine vegetation vigor. Scientists look at changes in vegetation vigor to determine maximum green-up (when the vegetation starts to grow the most) and maximum green-down (when it stops growing the most). The growing season is the time from the start of maximum green-up to the start of maximum green-down. This activity will look at two factors in a variety of ecosystems that can limit green-up and green-down.

What To Do and How To Do It

1. Conduct a class discussion to familiarize students with the graphs and land cover visualization.
2. Facilitate small group work in which students solve problems using the graphs.
3. Facilitate a class discussion based on presentations from each group during which the class attempts to reach a consensus on the explanation of limiting factors.

Step 1. Class Discussion

Use a class discussion to orient students to the visualization and graphs. Each visualization (Figures EA-P7-1, EA-P7-2, and EA-P7-3) should be an overhead transparency or printout that students can share. Figure EA-P7-1 shows the geographic regions that will be studied in this activity, with the regions of interest shaded to make them stand out. Figures EA-P7-2 and EA-P7-3 each depict three graphs of one year of data of vegetation vigor, surface temperature, and precipitation for two regions: North American tundra and South Africa wooded grassland (a shorthand for "Graminoid with Trees," the MUC term).

Start by introducing the geographic regions that will be studied, using Figure EA-P7-1. Follow this with an analysis of the graphs of vegetation vigor, temperature, and precipitation for one or two areas, marking values on the overhead to demonstrate how students will do the same on the *Work Sheet*. The class discussion will introduce students to the reasoning process they will use during the small group activities.

Vegetation Vigor of North American Tundra

1. Figure EA-P7-2a shows a graph of vegetation vigor for one year for the North American tundra. The world-wide range for vegetation vigor is between 0 and 0.65. To make sense of these values, present the following *landmark values*: rainforest has a value of about 0.50 year round, and desert has a value of about 0.08 year round. This tundra region varies from 0 to 0.20.
2. Focus on the *changes* for vegetation vigor throughout the year. Ask students to find (1) when it *starts* increasing, (2) when it peaks, (3) when it *starts* decreasing, and (4) when the largest increase and decrease occur. From January to April the tundra hardly grows at all. From April to August the vegetation vigor increases, and the largest increase is between June and July: this is called maximum green-up. The vegetation vigor peaks in August (maximum greenness), then decreases from August to November. The largest decrease is from September to October (maximum green-down). Overall, the decline occurs faster (over 2 months) than the increase (over 3 months).
3. Explain maximum green-up, maximum green-down, maximum greenness, and growing season and show them on the graph.
   - For the tundra, maximum greenup occurs between June and July, and maximum green-down occurs between September and October.
   - Students can confuse maximum green-up and green-down with maximum greenness, so be sure to explain the difference. Maximum greenness occurs in August.
   - The growing season is the period from the *start* of maximum green-up (June) and ending with the *start* of maximum green-down (September). Mark it on the graph.

Figure EA-P7-1: Limiting Factors in Ecosystems

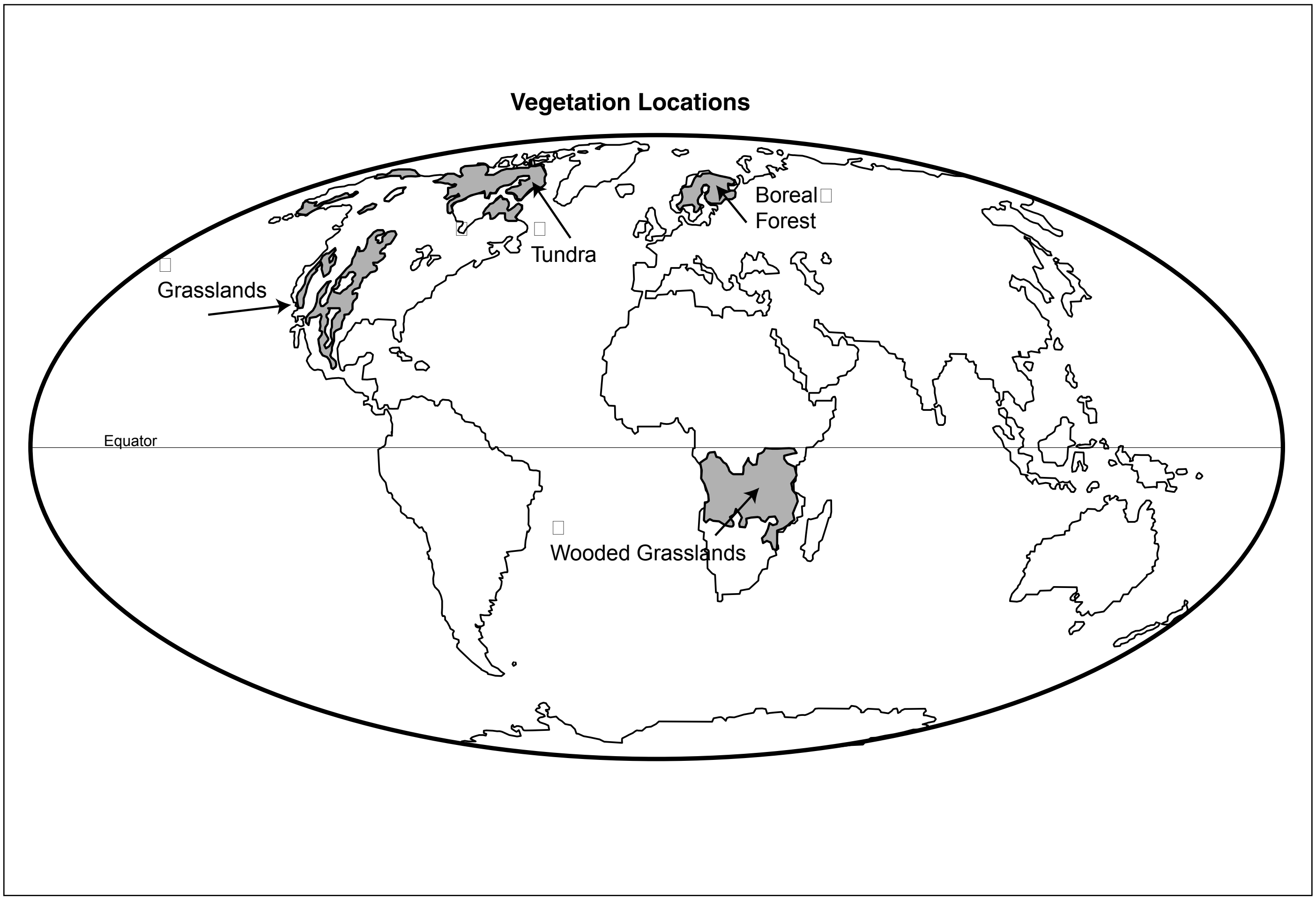


Figure EA-P7-2a, 2b, 2c

North American Tundra

Figure EA-P7-2a: Vegetation Vigor

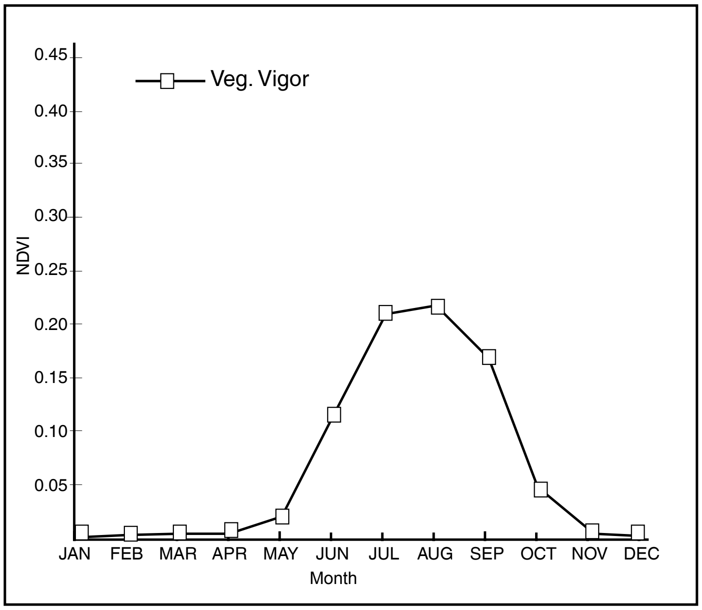


Figure EA-P7-2b: Vegetation Vigor vs. Surface Temperature

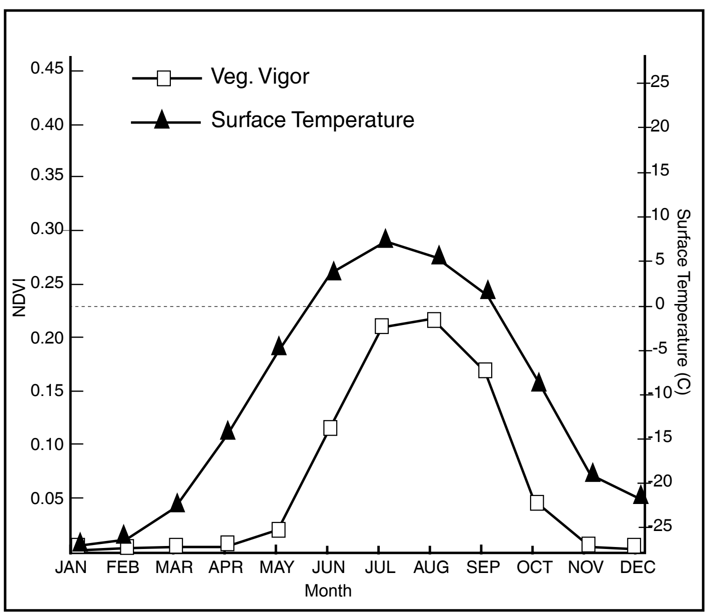


Figure EA-P7-2c: Vegetation Vigor vs. Monthly Precipitation

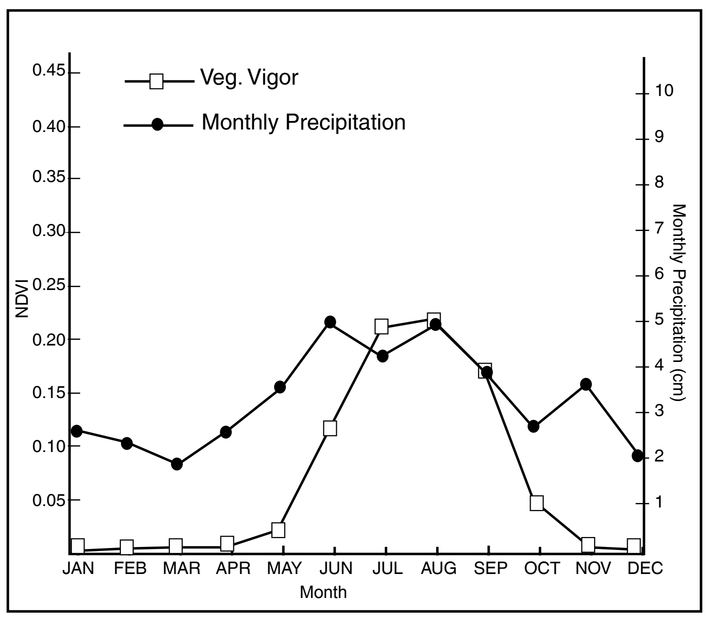


Figure EA-P7-3a, 3b, 3c

South African Wooded Grassland

Figure EA-P7-3a: Vegetation Vigor

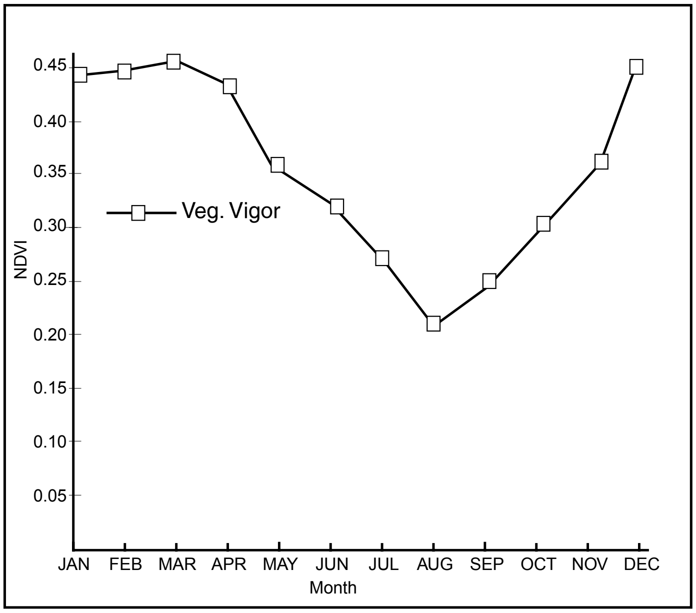


Figure EA-P7-3b: Vegetation Vigor vs. Surface Temperature

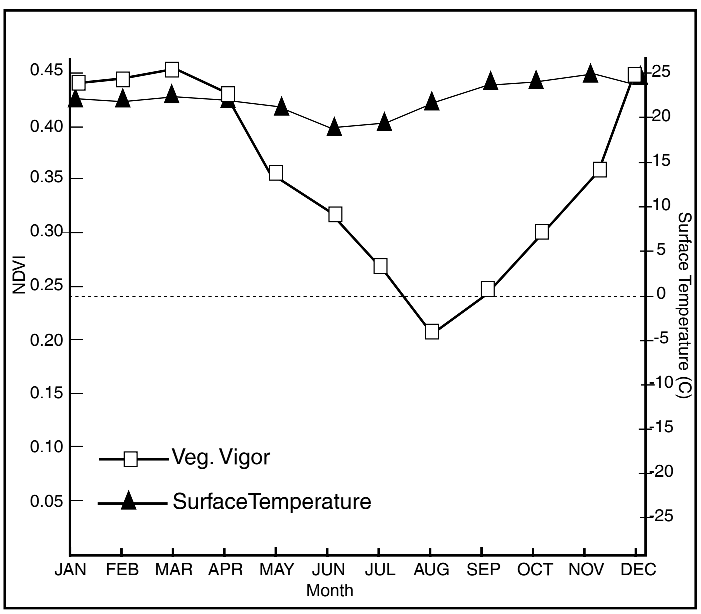
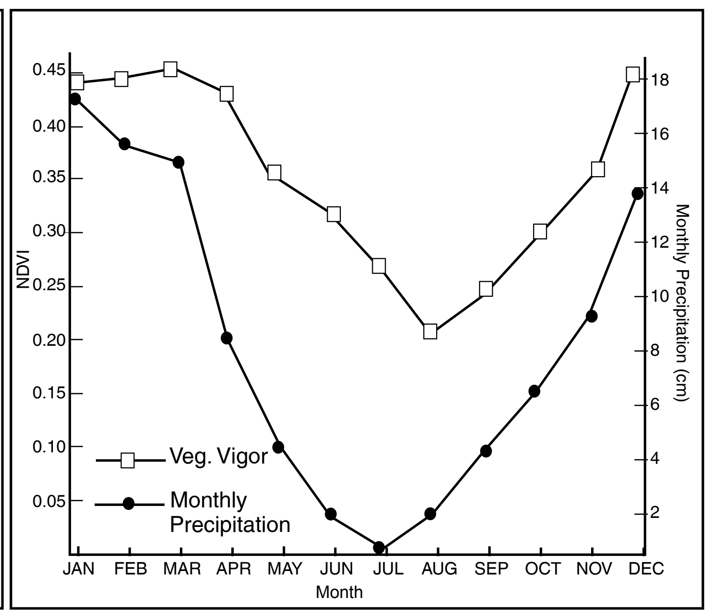


Figure EA-P7-3c: Vegetation Vigor vs. Monthly Precipitation



Limiting Factor for North American Tundra

1. **Understanding X-YY Graphs.** Figure EA-P7-2b shows a combined graph of vegetation vigor and surface temperature and Figure 2c shows vegetation vigor and precipitation. In order to make it easier to compare the overall shape of the curves, both data sets are shown on an X-YY graph. The vegetation vigor Y-axis is on the left and the axis for temperature or precipitation is on the right.
2. **Reading the Graphs.** To be sure they understand how to read the graph, ask students which lines correspond to vegetation vigor, surface temperature, and precipitation. For each line, ask students to identify the maximum and minimum values and to describe the overall shape. Students will be working with graphs that look like this in their *Work Sheets*.
3. **Temperature.** The growing season requires liquid water, so the *potential* growing season can be defined as the time when the surface temperature is above freezing. In this example, the surface temperature rises above freezing between May and June and falls below freezing between September and October so the potential growing season is May to October. Mark the potential growing season on the overhead.
4. **Precipitation.** Amount of rainfall also limits vegetation vigor. Use the graph to show when the maximum increase and decrease in monthly precipitation occur. For an ecosystem that is limited by precipitation, vegetation will grow the most when the total amount of rain in a month increases the most, and will decline when the rains cease. For the tundra, the maximum precipitation increase occurs between June and July, and the maximum decrease occurs between September and October. Mark these values on the overhead.
5. **Limited by temperature.** Ask students whether they think that the North American tundra ecosystem is limited by temperature or precipitation. Ask students to explain their reasons and point out evidence from the graphs that support their decision. In this example, the vegetation vigor period shown on the graph more closely corresponds to the potential growing season based on temperature. The decline in vegetation vigor does not correspond to a change in precipitation. Connect the values from the graph to the ecosystem by talking about how the tundra grows: the one month delay between the change in temperature and the start of the growing season is likely due to the time needed for ground thaw.

South Africa Grassland with Trees

Figures EA-P7-3a-3c show the same data for a region of wooded grassland in the Southern Hemisphere that is limited by precipitation.

1. **Vegetation Vigor.** Vegetation vigor for this region peaks in December and March, so these months have the maximum greenness values. Maximum green-up is between November and December, and maximum green-down is between April and May. This shows that the actual growing season is from November to April.
2. **Temperature.** The potential growing season covers almost the entire year because the temperature rarely dips below freezing.
3. **Precipitation.** The maximum increase in precipitation occurs between November and December, and the maximum decrease in precipitation occurs between March and April.
4. **Limited by Precipitation.** The evidence shows that growth in the South Africa wooded grassland ecosystem is limited by precipitation rather than by temperature. The temperature remains relatively constant and warm enough for the vegetation to thrive; yet the vegetation vigor shows large changes that match changes in precipitation.

Step 2. Group Problem-Solving

Students will analyze two different ecosystems in small groups, the North American Grassland (MUC Graminoid classification) and the Boreal Evergreen Forest. Use the visualization in Figure EA-P7-1 to show where these occur on Earth. Have students work in small groups to fill out the *Work Sheets*, determine which factor is limiting each ecosystem, and explain how they reached their conclusions. Instead of having each group analyze both ecosystems, you could assign half of the groups to analyze Boreal Evergreen Forest and the other half North American Grassland, and then have the groups present their results.

Step 3. Group Presentation

Bring students back together for a discussion of the results. Emphasize the important differences between the ecosystem dynamics of each region in terms of the limiting factors, and suggest other factors that might limit vigor for different regions. The GLOBE Earth as a System poster shows other factors. As students present their answers, watch for opportunities to encourage them to support their ideas with evidence from the graphs, what the graphs mean, and what they know about the ecosystems. Instead of focusing only on how they found the right answer, encourage students to think about the scientific meaning and to provide good evidence of why their answer is correct.

Further Investigations

Chart the limiting factors for your own ecosystem. Using the data that your school has collected as part of the atmosphere and phenology protocols, plot temperature, precipitation, and phenology data to decide whether growth in your local ecosystem is limited by temperature or precipitation, or by some other factor.

Another important limiting factor is light: both intensity and duration. You can explore how seasonal changes in light correspond to periods of high and low vegetation vigor on the graphs used in the *Work Sheets* by adding another line that indicates amount of daylight.

Resources

Using the spreadsheet option for the GLOBE Visualization Server, visualizations of land cover factors such as budburst may be analyzed in relationship to other variables such as temperature and soil moisture. Also, see the *Match the Biome* activity on the GLOBE Web Site (under News and Events). This activity asks students to connect climate diagrams showing temperature and precipitation with land cover types depicted in photographs.

Soil type (and the resulting moisture content) is also an important factor in plant growth and can act as a limiting factor in some ecosystems. The GLOBE Earth Systems Poster shows monthly values for soil moisture that can be compared to values for vegetation vigor on the same poster.

Limiting Factors in Ecosystems
Work Sheet

Names: ____

Directions

In this *Work Sheet*, you will analyze graphs of vegetation vigor (growth) for a specific region, along with graphs of temperature and precipitation for that region. You will fill in tables by reading the graphs to get the following *landmark values* for the region:

- **Maximum Greenness:** The peak of the graph that represents the highest value of the vegetation vigor. Some landmark values for different regions are 0.65 for a rainforest, and 0.05 for a desert. Knowing maximum greenness helps you to characterize the vegetation that you are studying.
- **Maximum Green-Up:** The period from one month to the next in which the largest increase in vigor occurs. This indicates when the growing season is underway the greatest amount.
- **Maximum Green-Down:** The period from one month to the next in which the largest decrease in vigor occurs. This indicates when the growing season is declining the greatest amount.

If you can correlate sharp changes in vegetation vigor with climate factors, you can determine the limiting factor for that region. For this activity, you will analyze data from only one year. Scientists would normally examine multiple years of data in order to draw conclusions about limiting factors.

North American Grassland

Part 1: Find Landmark Values for Vegetation Vigor

1. Figure EA-P7-4 is a combination of two X-Y graphs (called an X-YY graph). The line marked with open squares represents values for one year of vegetation vigor. The Y axis for this line is to the *left* of the graph. Using that line, fill in the landmark values for vegetation vigor in Table EA-P7-1.

2. The growing season is the time between the *start* of maximum green-up and the *start* of maximum green-down. Mark the growing season on the vegetation vigor line in Figure EA-P7-4 using a green pencil or crayon.

Part 2: Analyze Vigor, Temperature, and Precipitation Values

3. Plants grow best when the surface temperature is above freezing (0˚ C). Figure 4 also shows a graph of surface temperature for one year, represented by the line marked with triangles. The Y axis for this line is to the *right* of the graph. Using that line, fill in the landmark values for temperature in Table EA-P7-1.

   The time when the temperature is above freezing is the *potential* growing season. Mark the potential growing season on the temperature line in Figure EA-P7-4 using a red pencil or crayon.

4. Plants typically grow most when the most water is available. Figure EA-P7-5 shows another X-YY graph. The line marked with circles represents values for one year of precipitation. The Y axis for precipitation is to the *right*, while the vegetation vigor Y axis is to the *left*. Use Figure EA-P7-5 to fill in the landmark values for precipitation in Table EA-P7-1.

   Mark each line segment that represents a landmark value for precipitation using a blue pencil or crayon. Then, to make comparison easier for the next step, color the maximum green-up and maximum green-down line segments on the vegetation vigor line in Figure EA-P7-5.

Part 3: Find the Limiting Factor and Explain Your Choice

5. **Consider Temperature:** Use Figure EA-P7-4 and Table EA-P7-1 to answer the following:

   Does maximum green-up correspond to the beginning of the potential growing season?

   ____

   Does maximum green-down correspond to the end of the potential growing season?

   ____

6. **Consider Precipitation:** Use Figure EA-P7-5 and Table EA-P7-2 to answer the following:

   Does maximum green-up correspond to the month when precipitation increases the most?

   ____

   Does maximum green-down correspond to the month when precipitation decreases the most?

   ____

7. Using evidence from your analysis and your knowledge of the North American grassland ecosystem, discuss why you believe that growth in the ecosystem is limited by temperature or precipitation. Discuss both temperature and precipitation factors in your answer.

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North American Grasslands

Figure EA-P7-4: Vegetation Vigor and Surface Temperature by Month

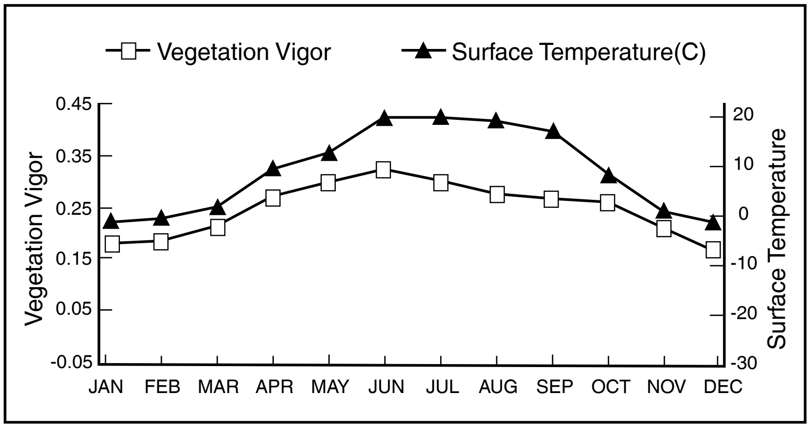

Figure EA-P7-5: Vegetation Vigor and Precipitation by Month

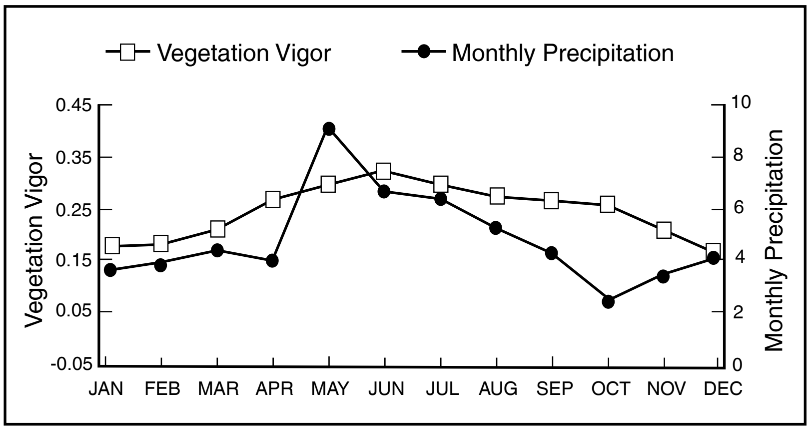

Table EA-P7-1: Landmark Values for North American Grassland

Landmark Values for Vegetation Vigor		
Maximum Greeness		
	Start Month	**End Month**
Maximum Green-up		
Maximum Green-Down		
Landmark Values for Temperature	**Start Month**	**End Month**
Temperature Above 0°		
Landmark Values for Precipitation	**Start Month**	**End Month**
Maximum Increase in Rainfall		
Maximum Decrease in Rainfall		

Boreal Evergreen Forest

Part 1: Find Landmark Values for Vegetation Vigor

1. Figure 6 is a combination of two X-Y graphs (called an X-YY graph). The line marked with open squares represents values for one year of vegetation vigor. The Y axis for this line is to the *left* of the graph. Using that line, fill in the landmark values for vegetation vigor in Table EA-P7-2.
2. The growing season is the time between maximum green-up and maximum green-down. Mark the growing season on the vegetation vigor line in Figure EA-P7-6 using a green pencil or crayon.

Part 2: Analyze Vigor, Temperature, and Precipitation Values

3. Plants grow best when the surface temperature is above freezing (0º C). Figure EA-P7-6 also shows a graph of surface temperature for one year, represented by the line marked with triangles. The Y axis for this line is to the *right* of the graph. Using that line, fill in the landmark values for temperature in Table EA-P7-2.

   The time when the temperature is above freezing is the *potential* growing season. Mark the potential growing season on the temperature line in Figure EA-P7-6 using a red pencil or crayon.
4. Plants typically grow most when the most water is available. Figure EA-P7-7 shows another X-YY graph. The line marked with circles represents values for one year of precipitation. The Y axis for precipitation is to the *right*, while the vegetation vigor Y axis is to the *left*. Use Figure EA-P7-7 to fill in the landmark values for precipitation in Table EA-P7-2.

   Mark each line segment that represents a landmark value for precipitation using a blue pencil or crayon. Then, to make comparison easier for the next step, color the maximum green-up and maximum green-down line segments on the vegetation vigor line in Figure EA-P7-7.

Part 3: Find the Limiting Factor and Explain Your Choice

5. **Consider Temperature:** Use Figure EA-P7-6 and Table EA-P7-2 to answer the following:

   Does maximum green-up correspond to the beginning of the potential growing season?

   ____

   Does maximum green-down correspond to the end of the potential growing season?

   ____
6. **Consider Precipitation:** Use Figure EA-P7-7 and Table EA-P7-2 to answer the following:

   Does maximum green-up correspond to the month when precipitation increases the most?

   ____

Does maximum green-down correspond to the month when precipitation decreases the most?

____

7. Using evidence from your analysis and your knowledge of the boreal evergreen forest ecosystem, discuss why you believe that growth in the ecosystem is limited by temperature or precipitation. Discuss both temperature and precipitation factors in your answer.

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Boreal Evergreen Forest

Figure EA-P7-6: Vegetation Vigor and Surface Temperature by Month

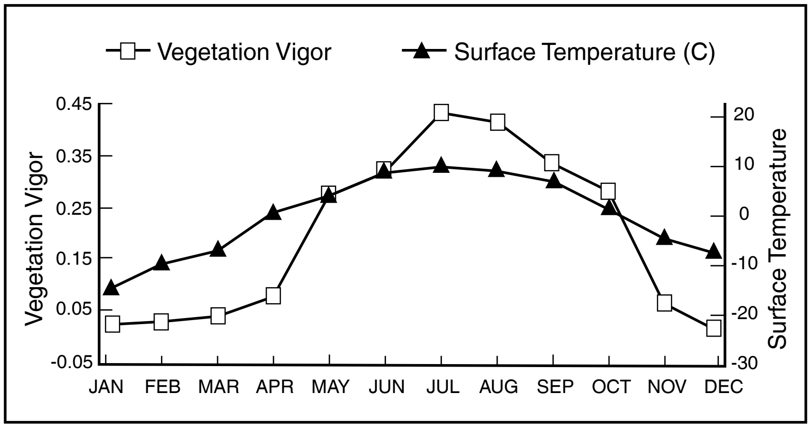


Figure EA-P7-7: Vegetation Vigor and Precipitation by Month

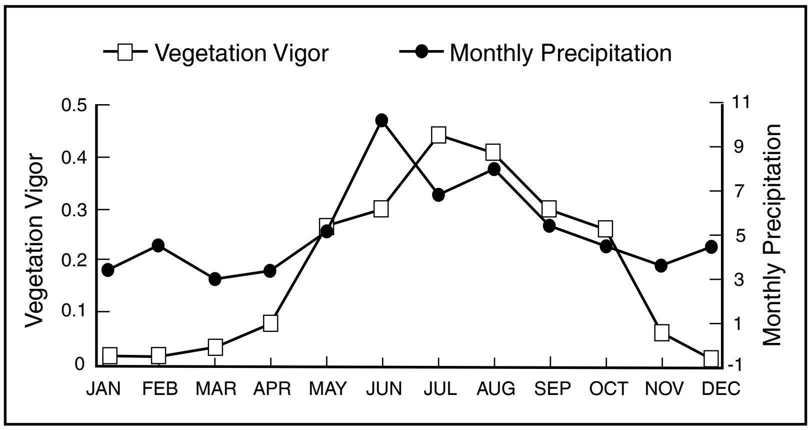


Table EA-P7-2: Landmark Values for Boreal Ever

Landmark Values for Vegetation Vigor		
Maximum Greeness		
	Start Month	**End Month**
Maximum Green-up		
Maximum Green-Down		
Landmark Values for Temperature	**Start Month**	**End Month**
Temperature Above 0°		
Landmark Values for Precipitation	**Start Month**	**End Month**
Maximum Increase in Rainfall		
Maximum Decrease in Rainfall		

Limiting Factors in Ecosystems
Rubric

For each criterion, evaluate student work using the following score levels and standards.

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, but needs improvement

0 = Answer is blank, entirely arbitrary or inappropriate

North American Grassland

Part 1: Landmark Values for Vegetation Vigor

1. Maximum Greenness (Table EA-P7-1)

Score Level	Description
3	Student identifies June as the month of maximum greenness.
1	Student answers some other month indicating that he/she became confused about the definitions.
0	Answer left blank or is arbitrary.

Maximum Green-Up (Table EA-P7-1)

Score Level	Description
3	Student identifies the start month as April and the end month as May.
1	Student confuses the definition with that of maximum green-up, or student fills in only the correct start month or end month, or start and end months are not consecutive.
0	Answer left blank or is arbitrary.

Maximum Green-Down (Table EA-P7-1)

Score Level	Description
3	Student identifies the start month as October and the end month as November.
1	Student confuses the definition with that of maximum green-up, or student fills in only the correct start month or end month or start and end months are not consecutive.
0	Answer left blank or is arbitrary.

2. Growing Season (Figure EA-P7-4)

Score Level	Description
3	Student identifies the growing season as between April and October and marks this on the graph in green.
1	Work is attempted, but student marks incorrect growing season on the graph,due to earlier errors.
0	Answer left blank or is arbitrary.

Part 2: Analyze Vigor, Temperature, and Precipitation Values

3. Temperature Above 0° (Table EA-P7-1)

Score Level	Description
3	Student identifies the start month as February and the end month as November.
1	Student confuses the temperature line with that of vegetation vigor, resulting in an answer of May to September, or student fills in only the correct start month or end month.
0	Answer left blank or is arbitrary.

Potential Growing Season (Figure EA-P7-4)

Score Level	Description
3	Student identifies the potential growing season as between February and November and marks this on the graph in red.
1	Work is attempted, but student marks incorrect potential growing season on the graph, due to earlier errors.
0	Answer left blank or is arbitrary.

4. Rainfall (Table EA-P7-1)

Score Level	Description
3	Student identifies the months with the maximum increase as April to May, and the months with the maximum decrease as September to October.
1	Student confuses the precipitation line with that of vegetation vigor, or student only marks the first month of the change (such as April) or the months marked are not consecutive.
0	Answer left blank or is arbitrary.

Rainfall (Figure EA-P7-5)

Score Level	Description
3	Student marks the line segment between April and May, and the one between September and October.
1	Student marks the entire period between April and October, or student marks lines incorrectly based on earlier errors.
0	Answer left blank or is arbitrary.

Maximum Green-Up and Green-Down (Figure EA-P7-5)

Score Level	Description
3	Student marks the line segment between April and May, and the one between October and November.
1	Student marks the entire period between April and October, or student marks lines incorrectly based on earlier errors.
0	Answer left blank or is arbitrary.

Part 3: Find the Limiting Factor and Explain Your Choice

5. Consider Temperature

Score Level	Description
3	The student offers a negative answer for these two temperature-related questions.
1	The student answers incorrectly based on previous errors.
0	Answer left blank or is arbitrary.

6. Consider Precipitation

Score Level	Description
3	The student offers a positive answer for these two precipitation-related questions.
1	The student answers incorrectly based on previous errors.
0	Answer left blank or is arbitrary.

7. Limiting Factors

Score Level	Description
3	Student answers “precipitation” and an explanation that stresses the following points: The periods of maximum green-up and green-down fall well within the potential growing season as defined by the temperature curve, so temperature cannot be the cause. The periods of maximum green-up and green-down correspond to the periods of maximum increase and decrease in the precipitation curve, so precipitation is the cause.
2	Student answers “precipitation” and an explanation is present but insufficient, offering minimal evidence or logical argument.
1	Either answer is given but with no rationale.
0	No answer given or an answer other than temperature or precipitation.

Boreal Evergreen Forest

Part 1: Find Landmark Values for Vegetation Vigor

1. Maximum Greenness (Table EA-P7-2)

Score Level	Description
3	Student identifies July as the month of maximum greenness.
1	Student answers some other month indicating that he/she became confused about the definitions.
0	Answer left blank or is arbitrary.

Maximum Green-Up (Table EA-P7-2)

Score Level	Description
3	Student identifies the start month as April and the end month as May.
1	Student confuses the definition with that of maximum green-down, or student fills in only the correct start month or end month, or start and end months are not consecutive.
0	Answer left blank or is arbitrary.

Maximum Green-Down (Table EA-P7-2)

Score Level	Description
3	Student identifies the start month as October and the end month as November.
1	Student confuses the definition with that of maximum green-up, or student fills in only the correct start month or end month or start and end months are not consecutive.
0	Answer left blank or is arbitrary.

2. Growing Season (Figure EA-P7-6)

Score Level	Description
3	Student identifies the growing season as between April and October and marks this on the graph.
1	Work is attempted, but student marks incorrect growing season on the graph, due to earlier errors.
0	Answer left blank or is arbitrary.

Part 2: Analyze Vigor, Temperature, and Precipitation Values

3. Temperature above 0º (Table EA-P7-2)

Score Level	Description
3	Student identifies the start month as May and the end month as October.
1	Student confuses the temperature line with that of vegetation vigor, resulting in an answer of some other month, or student fills in only the correct start month or end month.
0	Answer left blank or is arbitrary.

Potential Growing Season (Figure EA-P7-6)

Score Level	Description
3	Student identifies the potential growing season as between May and October and marks this on the graph.
1	Work is attempted, but student marks incorrect potential growing season on the graph, due to earlier errors.
0	Answer left blank or is arbitrary.

4. Rainfall (Table EA-P7-2)

Score Level	Description
3	Student identifies the months with the greatest increase as May to June, and the months with the greatest decrease as August to September.
1	Student confuses the precipitation line with that of vegetation vigor, or student only marks the first month of the change (such as May) or the months marked are not consecutive.
0	Answer left blank or is arbitrary.

Rainfall (Figure EA-P7-7)

Score Level	Description
3	Student marks the line segment between May and June, and the one between August and September.
1	Student marks the entire period between May and September, or student marks lines incorrectly based on earlier errors.
0	Answer left blank or is arbitrary.

Maximum Green-Up and Green-Down (Figure EA-P7-7)

Score Level	Description
3	Student marks the line segment between April and May, and the one between October and November.
1	Student marks the entire period between April and November, or student marks lines incorrectly based on earlier errors.
0	Answer left blank or is arbitrary.

Part 3: Find the Limiting Factor and Explain Your Choice

5. Consider Temperature

Score Level	Description
3	The student offers a positive answer for these two temperature-related questions.
1	The student answers incorrectly based on previous errors.
0	Answer left blank or is arbitrary.

6. Consider Precipitation

Score Level	Description
3	The student offers a negative answer for these two precipitation-related questions.
1	The student answers incorrectly based on previous errors.
0	Answer left blank or is arbitrary.

7. Limiting Factors

Score Level	Description
3	Student answers “temperature” and an explanation that stresses the following points: The periods of maximum green-up and green-down correspond directly to the potential growing season as defined by the temperature curve. The periods of maximum green-up and green-down do not directly correspond to the periods of maximum increase and decrease in the precipitation curve.
2	Student answers “temperature” and an explanation is present but insufficient, offering minimal evidence or logical argument.
1	Either answer is given but with no rationale.
0	No answer given or an answer other than temperature or precipitation.

Exploring the Connections

Introduction

Local Connections

LC1: Connecting the Parts of the Study Site

Students visit the study site, observe the different components of the Earth system and predict how they are connected to and affect each other.

*LC2: Representing the Study Site in a Diagram**

Students, either individually or in small groups, use their knowledge of their study site develop a diagram that illustrates the most important connections between the different components of the Earth system.

*LC3: Using Graphs to Show Connections**

Students use GLOBE student data to explore, understand, and communicate the connections between the components of the Earth system exist at the study site they are investigating.

*LC4: Diagramming the Study Site for Others**

Students compare and contrast the diagrams of their study site developed by individuals or small groups, and develop a class diagram of their study site that best communicates the most important connections between the components of the Earth system that exist there.

*LC5: Comparing the Study Site to One in Another Region**

Students compare and contrast diagram of their study site with a diagram developed for a region that is biogeographically different than their own.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Regional Connections

RC1: Defining Regional Boundaries

Students broaden their understanding of the Earth system by expanding their view of the Earth system from the local site to a regional system by identifying the boundaries of a regional Earth system.

*RC2: Effects of Inputs and Outputs on a Region**

Students examine the inputs and outputs of a regional scale Earth system and predict what would happen to that system if any of those inputs or outputs were changed.

Global Connections

GC1: Your Regional to Global Connections

Using global scale maps of winds and ocean currents students predict what region(s) in other parts of the world might be affected by their region.

*GC2: Components of the Earth System Working Together**

Using data about the components of the Earth system at the global scale, students discuss how the components interact to form the Earth system as a whole and use the water cycle to explore this in more detail.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction

The great value of the learning activities in *Exploring the Connections* is the opportunity they provide for students to integrate their knowledge from different GLOBE investigations and other studies. Students will synthesize a great deal of information and will be able to communicate a whole picture of what they have learned.

The learning activities in this section teach a new way of looking at the Earth – as a living system. Students learn to identify the parts of the system and the processes that connect them at the local, regional, and global scales. As GLOBE students become the experts in their study sites, they can be regarded as valuable sources of information to the scientific community. Since Earth system science is a relatively new discipline, students perceive their study areas in ways that even local scientists may not have.

Summary of Learning Activities

In *Exploring the Connections*, students develop their skills to represent their thinking visually, by diagramming – a powerful tool that can be used in any discipline. They diagram and describe their study site as an Earth system for other GLOBE schools. They begin with concrete, specific observations and move toward abstraction as they work through the activities. Students first observe their study site as a set of components and interactions, and they make lists of those interactions. They annotate a photograph of the study site, writing brief descriptions of the interactions they have observed. Then, based on those annotations, they make a semi-representational diagram of the study site. Students discover real evidence of the interactions among components by studying graphs of GLOBE data from their study site. They then compare their individual diagrams and work together to create a class diagram and study site description that they can share with others. Cooperative learning, discussion, and analysis of diagrams help all students develop their thinking and communication skills.

Each student and each class will develop a somewhat different diagram, and that is expected and encouraged. There are no right or wrong answers in the diagramming process, only exploration, discovery, consideration, expression, and reflection. The teacher's task is to guide the student in making her or his best diagram, one that expresses the student's own ideas most clearly and completely. Diagramming may bring out some students' strengths in both content and skills that may not have been apparent before. In order to help teachers direct the students in the process of diagramming, a guide, *Diagramming Earth as a System,* is included in this introductory section.

Many interactions among Earth system components at the local scale are the same as those at the regional and global scales. Once students understand their study site as a system, they can more easily comprehend ways in which their region and the whole Earth operate as systems.

In activities at the regional scale, students identify and delineate the boundaries of a region for study as an Earth system. Different kinds and sizes of regions lend themselves to this study. Going through the identification process reflects and strengthens students' understanding of what makes a system, as students must justify their choice of regional boundaries. Once they have identified their region, they consider what enters and leaves it, its inputs and outputs, and the implications of changes in those inputs and outputs.

Expanding their scope to the global scale, students identify specific means and pathways – related to wind and water – by which their region is connected to others across the globe. They identify major components of the Earth system at the global scale, trace the pathway of water throughout the system's major components, and make a diagram of the pathway as an example of interconnectedness at the global scale.

Activities Are Organized by Scale

Activities are organized in three parts according to scale: local, regional, and global scales. The titles of the sections reflect these scales as follows: *Local Connections, Regional Connections, and Global Connections.*

Local Connections: How Can We Represent Our Study Site as a System to Other GLOBE Schools?

LC1: *Connecting the Parts of the Study Site*

LC2: *Representing the Study Site in a Diagram*

LC3: *Using Graphs to Show Connections*

LC4: *Diagramming the Study Site for Others*

LC5: *Comparing the Study Site to One in Another Region*

Regional Connections: In What Ways Is Our Region an Open System?

RC1: *Defining Regional Boundaries*

RC2: *Effects of Inputs and Outputs on a Region*

Global Connections: How Can We Describe the Earth as a System?

GC1: *Your Regional to Global Connection*

GC2: *Components of the Earth System Working Together*

Implementation Considerations

Curriculum

Teachers can conduct these learning activities in the context of biology, chemistry, Earth science, human or physical geography, meteorology, or oceanography. Writing and visual skills are integral parts of the activities.

Sequence

The activities have been designed to be done in sequence, and it is strongly recommended that teachers take students through the activities that way, particularly within each section. However, if necessary, each of the activities can stand alone.

Student Groups

Much of the work involved in the activities can be done either individually or in groups. The general pattern in these activities is that students work alone, then in groups, then as a class. If students do their initial work individually, the teacher will have the means of assessing prior knowledge. The teacher may wish to assign individual work periodically to test progress and comprehension.

Student Misconceptions

It has become clear in recent years that it is critical for teachers to discover and deal with student misconceptions about material being covered. If that step is neglected, students will retain their misconceptions and will not absorb the new material. Students' ideas are connected as a web; students will hold on to their previous ideas until they have a complete new set. These learning activities are designed so that initial discussions, student work, and student self-assessments will help to expose misconceptions. Teachers can use those products as a baseline for instruction.

Some specific student misconceptions students have about systems are known. From the American Association for the Advancement of Science, Project 2061, *Benchmarks for Science Literacy*: "Children tend to think of the properties of a system as belonging to individual parts of it rather than as arising from the interaction of its parts. A system property that arises from interaction of parts is therefore a difficult idea." (p. 262). This "difficult idea" is addressed at the very start of these learning activities. In Activity LC1, students list interconnections among the major components of their study site, making predictions about how the characteristics of one component might change if the characteristics of another component were to change. In LC2 and LC4, they develop diagrams of these interconnections. In RC2, students again make predictions about how components of a system might change if another component were to change, this time at the regional scale.

From *Benchmarks for Science Literacy*: "Also children often think of a system only as something that is made and therefore as obviously defined. This notion contrasts with the scientific view of systems as being defined with particular purposes in mind....(p. 262). Help in addressing this misconception can be found in Activity RC2, in which students identify and define their own region for study as a system.

Special Note

Scientists use the terms "atmosphere" for air, "hydrosphere" for bodies of water, "pedosphere" for soil, and "biosphere" for all living things. Pedosphere in particular may be an unfamiliar term. These terms are introduced in the second activity of the local scale section; teachers may wish to introduce them sooner or later than that.

Alignments to other GLOBE Learning Activities

Alignments to Local Connections Activities

All the activities listed below reinforce the concept that components of the Earth system change each other through their interactions. This concept, central to the activities in this section is key to an understanding of systems.

Hydrology Investigation: *Water Walk*

This activity helps students become familiar with the Earth's bodies of water and the differences in characteristics of water. Students learn that the characteristics of bodies of water are closely related to the characteristics of the surrounding land.

Hydrology Investigation: *The pH Game*

Students learn that the level of pH influences the vegetation and wildlife in a site, and is itself influenced by different factors in the rocks and soil, human activities, the atmosphere (precipitation), and the amount of water in the landscape.

Soil Investigation: *Just Passing Through*

Students develop an understanding of some of the relationships between water and soils of different types.

Earth as a System Investigation: Seasons and Phenology: *What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?*

Teachers and students share seasonal marker observations, which are the various changes that mark transition points in the annual cycles of seasons. (Examples are the first snowfall, the beginning of monsoon rains, and the summer solstice.) Students compare GLOBE data with the observations they study. The activity promotes collaborations among GLOBE classes and helps teachers and students learn how to work with the GLOBE data system and GLOBEMail email. It also helps teachers and students learn how the protocols are interconnected.

All of the following activities strengthen the student's ability to compare the characteristics of Earth system study sites in different parts of the globe.

Soil Investigation: *Soil and My Backyard*

Student explore soil and soil properties, discovering the variability of soils and how they are formed.

Soil Investigation: *A Field View of Soil - Digging Around*

Students discover that variations in the landscape, such as in slope, shade, and plants, can affect soil properties, and that every soil is unique every place on Earth.

Earth as a System Investigation: Seasons and Phenology: *What Are Some Factors That Affect Seasonal Patterns?*

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

Earth as a System Investigation Seasons and Phenology: *How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?*

Students use GLOBE visualizations to display student data on maps and explore seasonal changes in regional and global temperature patterns across the Earth. They learn that temperatures vary from one location to another around the world and that local latitude, elevation and geography affect seasonal temperature patterns.

Alignments to Regional Connections Activities

Hydrology Investigation: *Model a Catchment Basin*

Watersheds provide useful boundaries for study of the Earth system, and this activity introduces students to their watershed and how it works. It also builds their skills of interpreting maps and images, as these are used to help construct a three-dimensional model of a watershed.

Alignments to Global Connections Activities

An Activity Guide accompanies the GLOBE Earth System Poster, *Exploring the Connections in a Typical Year.* The Guide describes how to help students explore patterns in the data displayed on the poster. Students find annual changes, relationships among types of data, and global patterns, and they make connections with GLOBE data.

Student Learning Goals and Alignment with National Standards, AAAS Project 2061 Benchmarks, and TIMMS

Student Learning Goals

Exploring the Connections accomplishes several goals at once. It teaches essential concepts and skills according to national standards; it introduces students to the new discipline of Earth system science; and it provides tools for students to construct an integrated conceptual framework for all their work with GLOBE. Just as Earth system scientists investigate relationships among several components of the Earth system and the scientific disciplines such as atmospheric science, oceanography, geology, and biology, devoted to them, so students investigate relationships among all GLOBE investigations. No one investigation is emphasized over any other. However, the design of this set of learning activities does allow students to discover and express their particular strengths in any given content area. Students also expand their abilities to demonstrate what they know in a variety of ways: verbally, visually, and in written form.

The objective for students in the Local Connections activities is to communicate to others the uniqueness of their study site as an Earth system. Teachers and students may also wish to describe their study site interactions to other audiences, such as policy makers.

The goal of Earth system science is to better understand the components and processes that shape the environment of the Earth, so that we can learn to understand our environment and make informed decisions to manage it. After going through these activities, students will have increased their understanding and will have developed their ability to make informed decisions about their environment. For example, they can review and analyze GLOBE measurements they and others have taken over time and consider whether or not any long-term changes are indicated. They can ponder the effects of those changes might be and how they should respond. Earth system science is a new scientific discipline, and as students teach others this new way of looking at the Earth, and they will learn it more thoroughly themselves.

Alignment with National Standards

The following table indicates the particular standards as described in the National Science

Education Standards, addressed by each of the *Exploring the Connections Learning Activities.*

Student Learning Assessment

Assessment rubrics are included at the end of each learning activity. These can be used by the teacher to determine the extent to which students have understood the concepts and mastered the skills that were examined or used in the activity and to identify where there is still confusion. The assessments can also be used by the students to help them reinforce what they have learned and to identify areas of weakness.

Integrated problems are included in the appendix of this chapter that are designed to help the teacher assess if students can take the content material and skills they have learned through conducting the *Exploring the Connections Learning Activities* and apply them to other situations. Assessments have been developed for various levels of students.

Coverage for Exploring the Connections

National Science Education Standards	Learning Activity								
	LC1	LC2	LC3	LC4	LC5	RC1	RC2	GC1	GC2
Earth And Space Sciences									
Changes in Earth and Sky (K-4)									
Weather changes from day to day and over the seasons	□	□	□	□	□	□	□	□	□
Energy in the Earth System (9-12)									
The sun is the major source of energy at Earth's surface	□	□	□	□	□	□	□	□	□
Solar insolation drives atmospheric and ocean circulation	□	□	□	□	□	□	□	□	□
Geochemical Cycles (9-12)									
Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere)	□	□	□	□	□	□	□	□	□
Physical Sciences									
Energy: Transfer and Conservation (5-8)									
Heat energy is transferred by conduction, convection and radiation	□	□	□	□	□	□	□	□	□
Heat moves from warmer to colder objects	□	□	□	□	□	□	□	□	□
Sun is a major source of energy for changes on the Earth's surface	□	□	□	□	□	□	□	□	□
Energy is conserved	□	□	□	□	□	□	□	□	□
Chemical Reactions (9-12)									
Chemical reactions take place in every part of the environment	□	□	□	□	□	□	□	□	□

Coverage for Exploring the Connections (continued)

National Science Education Standards	Learning Activity								
	LC1	LC2	LC3	LC4	LC5	RC1	RC2	GC1	GC2
Life Sciences									
The Characteristics of Organisms (K-4)									
Organisms can only survive in environments where their needs are met	□	□	□	□	□	□	□		□
Earth has many different environments that support different combinations of organisms	□	□	□	□	□	□	□		□
Organisms and their Environments (K-4)									
Organisms' functions relate to their environment	□	□	□	□	□	□	□		□
Organisms change the environment in which they live	□	□	□	□	□	□	□		□
Humans can change natural environments	□	□	□	□	□	□	□		□
Life Cycles of Organisms (K-4)									
Plants and animals have life cycles	□	□	□	□	□	□	□		□
Structure and Function of Living Systems (5-8)									
Ecosystems demonstrate the complementary nature of structure and function	□	□	□	□	□	□	□		□
Regulation and Behavior (5-9 & 9-12)									
All organisms must be able to obtain and use resources while living in a constantly changing environment	□	□	□	□	□	□	□		□
Populations and Ecosystems (5-8)									
All populations living together and the physical factors with which they interact constitute an ecosystem	□	□	□	□	□	□	□		□
Populations of organisms can be categorized by the function they serve in the ecosystem	□	□	□	□	□	□	□		□
Sunlight is the major source of energy for ecosystems	□	□	□	□	□	□	□		□
The number of animals, plants and microorganisms an ecosystem can support depends on the available resources	□	□	□	□	□	□	□		□
The Interdependence of Organisms (9-12)									
Atoms and molecules cycle among the living and non living components of the ecosystem	□	□	□	□	□	□	□		□
Energy flows through ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers)	□	□	□	□	□	□	□		□
Organisms both cooperate and compete in ecosystems	□	□	□	□	□	□	□		□
The population of an ecosystem is limited by its resources	□	□	□	□	□	□	□		□
Humans can change ecosystem balance	□	□	□	□	□	□	□		□
Matter, Energy, and Organization in Living Systems (9-12)									
Energy for life derives mainly from the sun	□	□	□	□	□	□	□		□
Living systems require a continuous input of energy to maintain their chemical and physical organizations	□	□	□	□	□	□	□		□
The Behavior of Organisms (9-12)									
The interaction of organisms in an ecosystem have evolved together over time	□	□	□	□	□	□	□		□

Diagramming Earth as a System

Diagramming is a powerful way for your students to better understand Earth as a system. Diagrams enable students to embody their understandings in an illustration and to evolve their thinking as their diagrams encompass deeper understandings of the components and connections of Earth as a system. Further, diagrams provide you, the teacher, with a window on student understandings (and misunderstandings) as evidenced in their diagrams.

Using this process, students progress from literal drawings to more symbolic and abstract representations. This progression is a sign of learning, which results from students working over a few weeks to refine their diagrams as personal expressions and from students digesting the science concepts related to components and interconnections of Earth as a system.

Students draw their diagrams in the context of one or more visits to their GLOBE study sites. They base their drawings on their analysis of data from their own site and other sites throughout the world. As in the examples which follow, students should label their diagrams to designate the Earth system components and interconnections. Initially your students (especially elementary school students) might simply label components (such as tree, river, cloud). Over time, students can add labels showing some of the connections (such as "leaves fall and decompose, become part of the soil"). At the most advanced level of understanding, students use arrows, labels, and comments to illustrate systems (such as the full water cycle). Please refer to the description of Earth as a system at the beginning of this chapter.

As you work with your students, it may be helpful to consider diagramming in four phases, as described and illustrated on the pages that follow. In general, your students should progress from one phase to the next as their learning and understanding increase. Of course, individual student diagrams will differ, and older students may progress to abstract levels more quickly.

Discuss the literal illustration (Figure EA-EX-2) with your students. Ask them how they might simplify the illustration further in order to focus on the components, connections, and systems (Figure EA-EX-3). For example, instead of drawing many trees, students should draw just one tree. This forces students to decide which are the most important components, connections, and systems at their study site, that may be different at another study site. Although you might expect that more advanced understanding would lead to more complexity, in reality scientists often search for the simple essence of a system in order to understand it better.

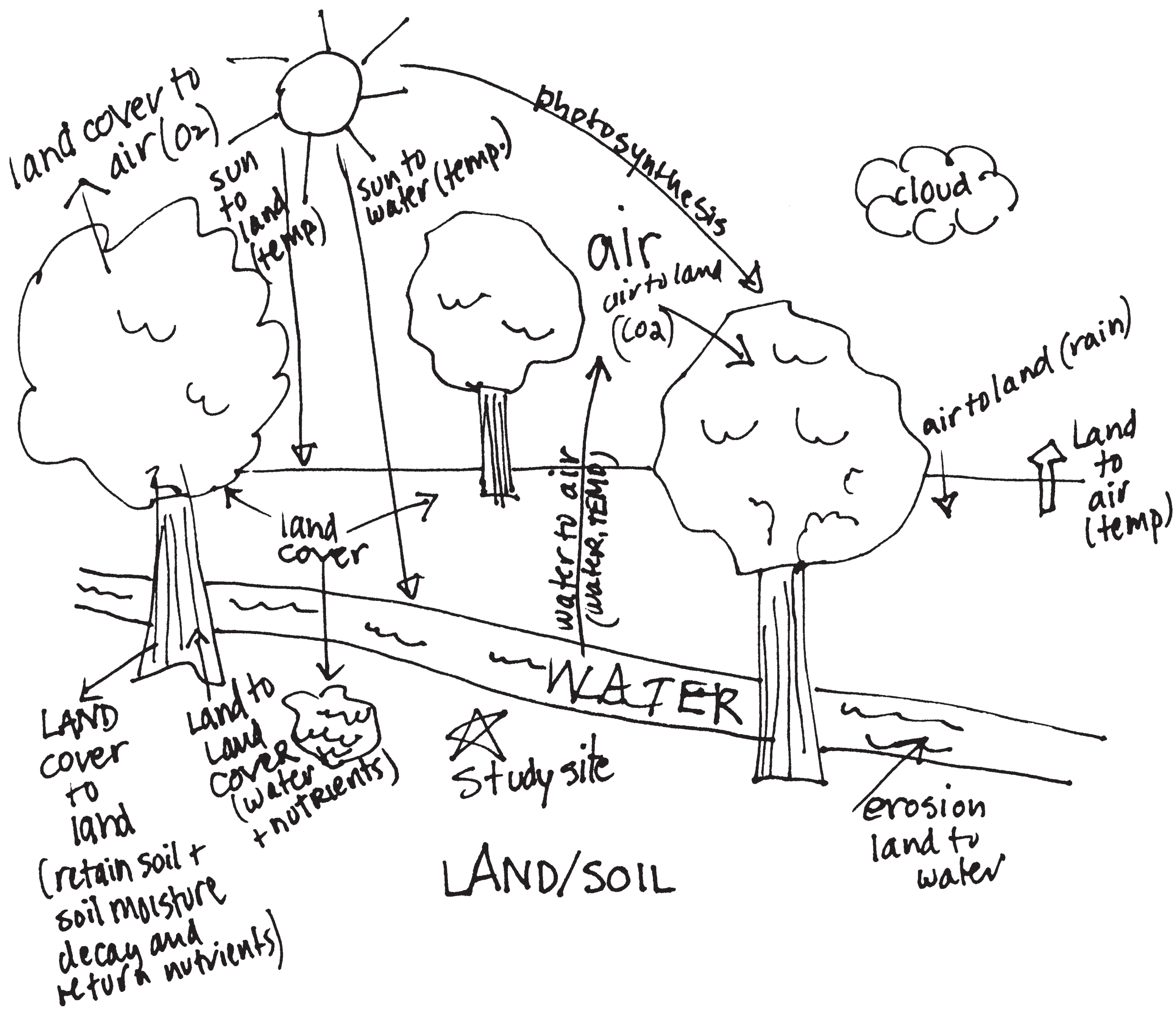
At the most advanced level, students move to a more abstract representation of the system. The example here (Figure EA-EX-4) reduces the diagram to the four major components of the Earth system (atmosphere, hydrosphere, pedosphere, and biosphere), with arrows showing the connections. This most simplified representation enables students to see the top-level view of Earth as a system. In reality, these broad domains and arrows imply underlying details. Such abstract representations embody a deeper understanding of the internal complexities of the full system.

The diagrams your students create serve multiple purposes. Most importantly, they help your students learn and develop their understanding of Earth as a system. Also, they provide you, as the teacher, with a powerful and convenient assessment tool, to see (literally) what your students are learning. In addition, diagrams are a vehicle of communication – they help your students (and scientists) share their own perceptions and models of Earth as a system. As such, each type of diagram serves its own purpose. There is no single correct diagram. It depends on what one wants to communicate. A literal diagram conveys the details of the particular site. An abstract diagram with arrows of different widths conveys relative quantities. And a highly simplified diagram with circles for the four major components conveys the top-level understanding of the system. You, your students, and scientists choose among the various types depending on what aspect of Earth as a system is to be communicated and focused on.

Figure EA-EX-1: Phase One – Photograph with Labels

In this example (Figure EA-EX-1), students took a photograph of the study site (a stream flowing down the side of mountain), and then added labels with some descriptive comments. This approach is an easy way to get started, as the photographs are easy to use (requiring no drawing), the labeling can be done in the classroom, a set of photographs can show different aspects of the site, and the photos include many details that can lead to further discussion in the classroom. (You may want to take one or more photos to a local copy shop for overhead transparencies to support classroom discussions.)

Figure EA-EX-2: Phase Two – Literal Illustration



In this phase (Figure EA-EX-2), students move from the photo to illustration. Ideally, the illustration is done at the study site, while the students observe the site and pay close attention to what they see. By drawing in the field context, students are encouraged to notice more and more about their study site. When students add labels, including both the components (river, soil) and the interconnections (water from the river goes into the soil and then into the roots of the plants), they are summarizing what they see as important. If students put the labels on a clear transparency overlay, they can evolve their labels over time.

Figure EA-EX-3: Phase Three – Simplified Illustration

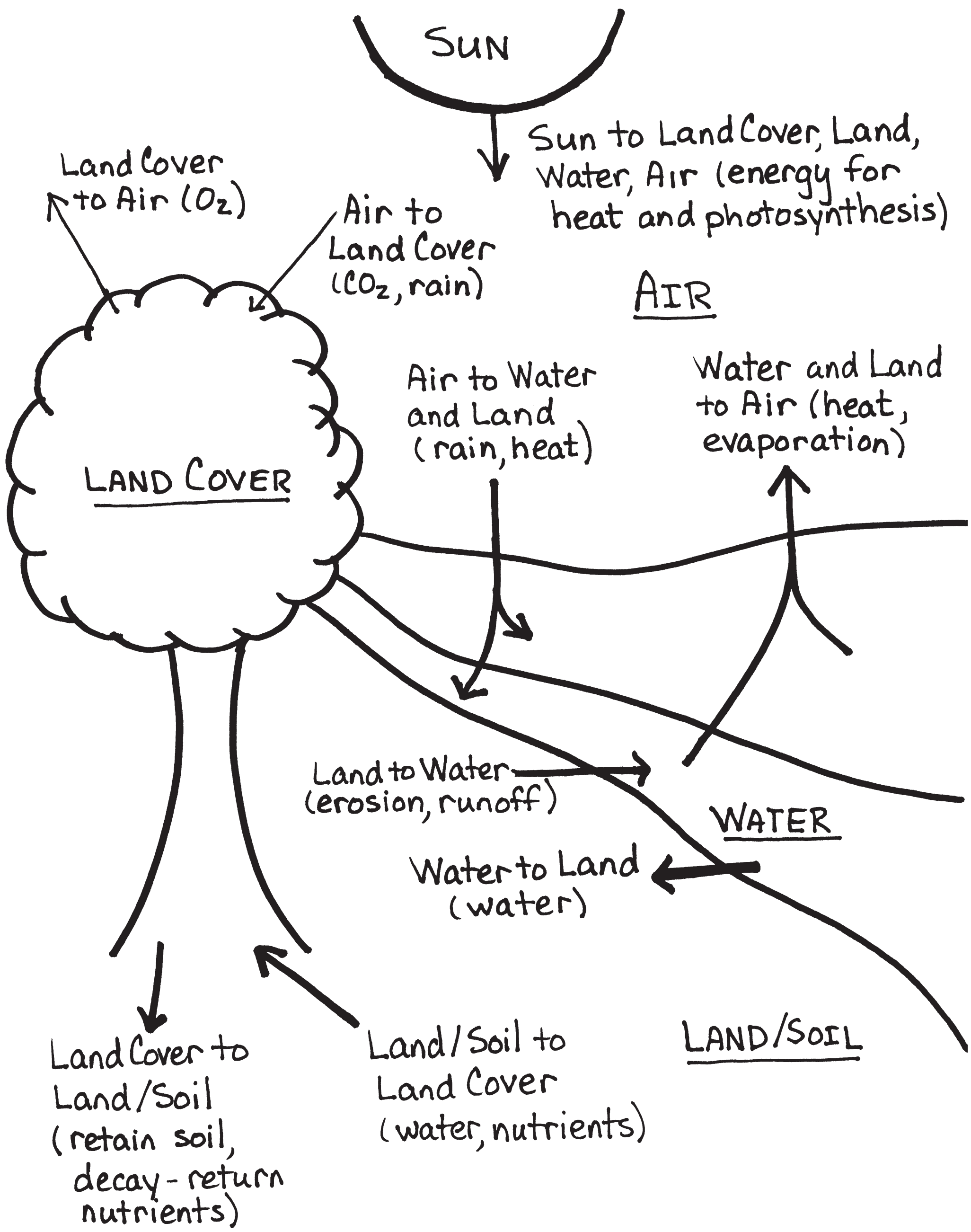
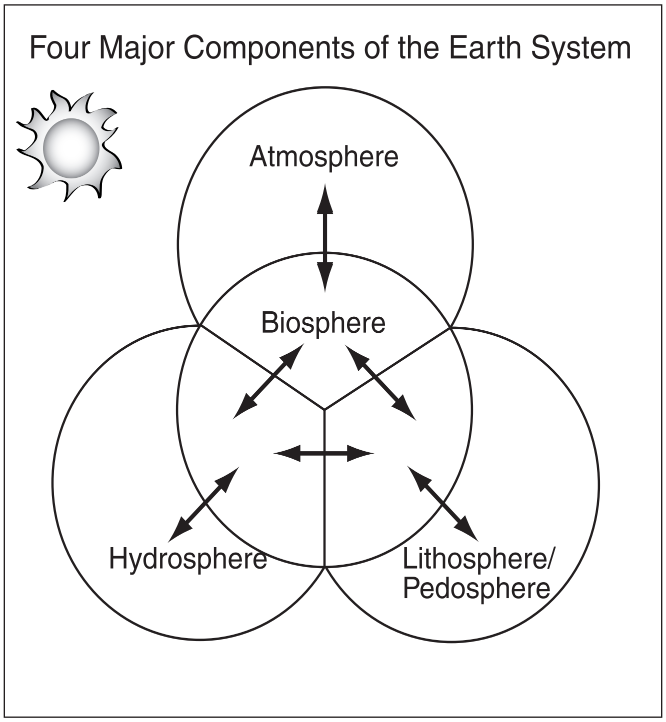


Figure EA-EX-4: Phase Four – Abstract Representation



Drawing Conclusions from Graphed Data

In activity LC3, *Using Graphs to Show Connections,* we suggest using graphs to understand the connections between air temperature on one hand and either water temperature or soil temperature on the other. But drawing conclusions from graphed data is not always easy. So here we provide some suggestions on using graphs effectively to understand single variables and the relationships among variables.

Getting Oriented to the GLOBE Graphing Conventions

First, we should get oriented as to how the GLOBE graphs organize and present information. In this analysis we use only the line graphs produced by the GLOBE Web site. All these graphs have the same format. Before beginning analysis with the graphs, we should understand these format conventions.

Look at Figure EA-EX-5 and notice:

- The GLOBE icon at the upper left identifies this as a GLOBE graph.
- The name of the school that submitted the data appears at the top of the graph.
- The name of the GLOBE measurement being graphed appears at the bottom of the graph, e.g. Maximum Air Temperature.
- Left of the name of the measurement is the icon used to mark the data on the graph, e.g. a triangle.
- To the right of the measurement name is the unit of measurement, e.g. ˚C(elsius).
- The beginning date of the graph (month/day/year) appears at the bottom left, e.g. 1/1/1998.
- The graph has dotted guidelines to help you read the data points in relation to the x- and y-axis scales.
- The GLOBE graphing program connects the observations with a line to make it easier to follow the trend of the data.

The graph has two axes. The x-axis (horizontal) has *time* increasing to the right. The scale on this axis increases by days or months, over one or more years. The y-axis (vertical) shows the range of values that the variable being graphed goes through over the time it was measured.

Figure EA-EX-5 shows the maximum air temperature at Reynolds Jr. Sr. High School over the course of a year. What information about the temperature at Reynolds Jr. Sr. High School can we get from this graph?

1. What time period does this graph cover? In this case it is one year, beginning with 1/1/98. (Count 3 months after 10/1 to find the end of the year.)
2. Next look at the frequency of observations. In this case it is about once a day, which indicates that the students took the temperature every day or so.
3. Then ask, “Do the data vary smoothly from one point to the next or do the points jump around?” In the case of Reynolds Jr. Sr. High School, the maximum daily temperature jumps up and down a lot. But how much?
4. We can estimate the daily maximum temperature variation by sketching a line to connect the highest points and another line to connect the lowest points. The difference between the “high line” and the “low line” shows the range of the daily maximum temperature change. This range may vary during the year. If it does, the high and low lines will move closer together or farther apart.
5. Next we want to consider how the daily maximum temperature *changes* over the entire period of time shown in the graph. What are the lowest and highest daily maximum temperatures and when do they occur? Here are three ways to find out:
   a. Just inspect the graph visually.
   b. Create a monthly average of the daily maximum temperature values and plot the monthly averages on the graph. Then inspect the pattern of averages.
   c. Take the maximum and minimum daily maximum temperature curves you drew in step 4 and average the values at

different times of year. From this, estimate the maximum and minimum daily maximum temperature.

Through the use of the graph of the daily maximum temperatures at Reynolds Jr. Sr. High School in 1998 we have determined:

- the variation in the daily maximum temperatures and
- the seasonal range of the daily maximum temperatures.

But, this is based on information for only one year, 1998. Would the pattern hold up in other years?

We can also use line graphs of this kind to examine how two variables are related. For this, we need a graph with two variables, which is discussed in the next section.

Exploring Relationships Among Two Variables Using a Graph

One way to explore the relationship among two variables is to plot those variables on the same graph. But when reading such a graph we need to consider whether the variables are of the same kind or not. (By "same kind" we mean that they measure the same quantity in the same units. Air temperature and water temperature are the "same kind" of variable because they both measure temperature in ˚C. Soil pH and water pH are the "same kind" because they both measure acidity in pH units.)

Two Variables of the Same Kind

In Figure EA-EX-6, both sets of data are *temperatures* and both are measured in the *same units, ˚C*. Therefore, both the right and the left y-axes are scales of temperature in ˚C. Since the scales are the same, there is no problem comparing the two variables.

Let's look at how the two temperatures (air and water) change over a long time (a year) and over a short time (a week or two).

Over the course of the year we see in the surface water temperatures the familiar seasonal cycle that we saw in the daily maximum air temperatures, shown also in Figure EA-EX-5. However, there are some differences.

1. The first difference is that the water temperature does not "vary" as much as the air temperature. You should be careful not to over-interpret this aspect of the graph. Air temperatures are measured every day and so they may appear to jump around more than water temperatures that are measured only once a week. You cannot tell how much water temperatures may have varied between observations.

   There also seems to be a relationship on shorter time scales between the surface water temperature and the daily maximum air temperature. Look, for example, at mid-March. During that time the daily maximum air temperatures are relatively low compared to the general trend of the air temperatures during the spring. At the same time the weekly surface water temperatures are also relatively low compared to the general trend of the temperatures during the spring. This particular example shows an effect which lasts a few weeks. If you now look more closely at the data through the year you will see that at times of relatively low or high surface water temperatures there are also relatively low or high daily maximum air temperatures.

2. There is another difference between the surface water temperature and the daily maximum surface air temperature when viewed through the year. The range of the water temperature is smaller than the range of the air temperature. Look carefully at the temperatures during the summer. The daily maximum air temperature is higher than the surface water temperature most of the summer. Now look carefully at the temperatures during the winter. The daily maximum air temperature and the surface water temperature are generally within the same range during the winter. As a result, the range of temperatures of the water through the year is smaller than the range of air temperatures.

Figure EA-EX-5: Daily Maximum Air Temperature at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for

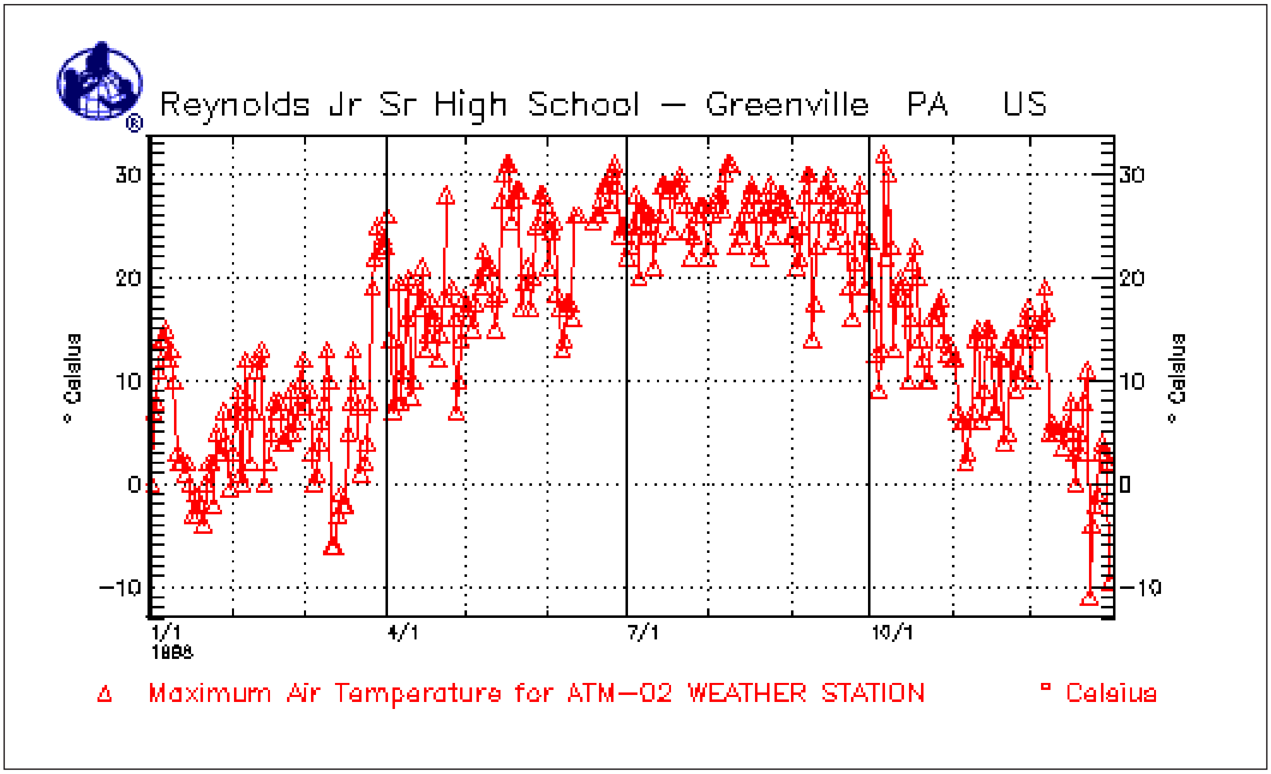


Figure EA-EX-6: Surface Water Temperature and Daily Maximum Air Temperature at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for 1998

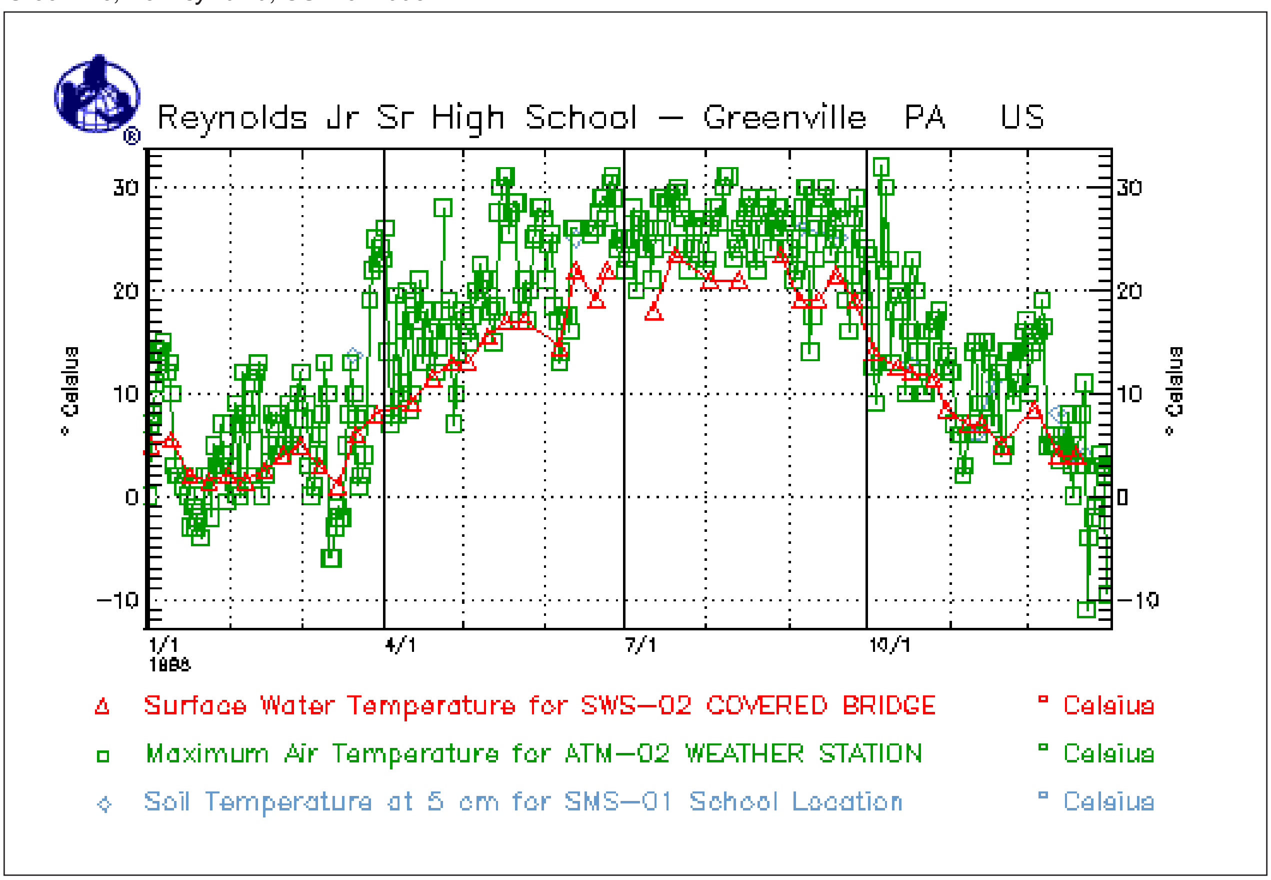


Figure EA-EX-7: Surface Water Temperature and Surface Water Dissolved Oxygen at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for 1998

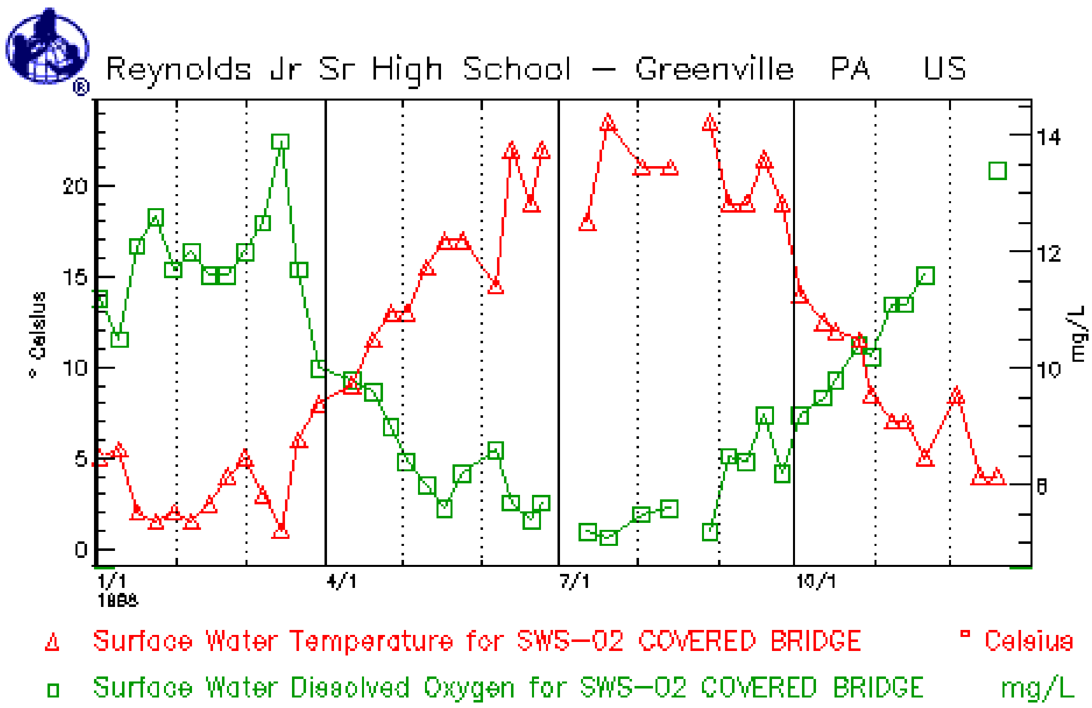
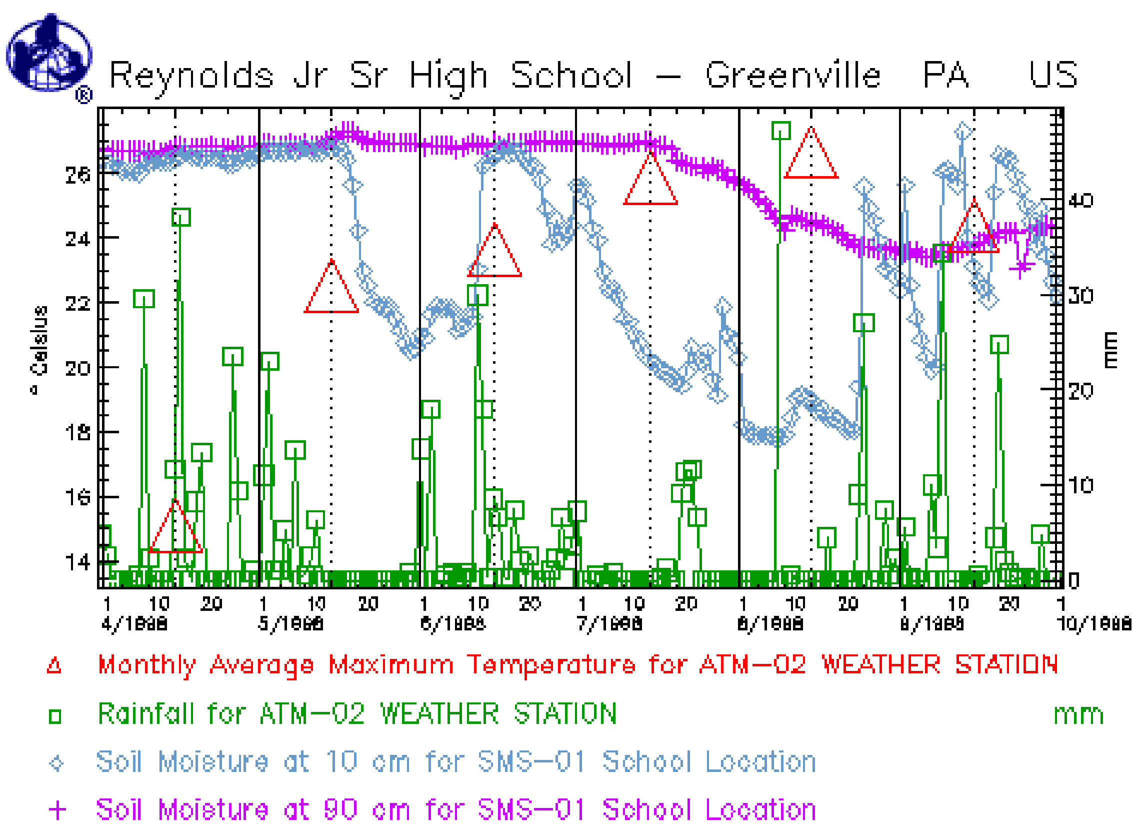


Figure EA-EX-8: Monthly Averages Maximum Temperature, Daily Precipitation, and Soil Moisture at 10 cm and 90 cm at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA from April 1, 1998 to October 1, 1998.



Two Variables of Different Kinds

Figure EA-EX-7 shows two variables that are of different kinds: temperature shown in ˚C and dissolved oxygen (DO) in mg/L. Therefore, the y-axis on the right side is different from that on the left side of the graph. Each y-axis has a data scale that covers the range of variation of the variable that is being plotted on the graph using that scale. On this graph the range of the surface water temperature is between -1˚ C and 25˚ C, the minimum and maximum on the y-axis scale. The range of the dissolved oxygen data, as seen on the right hand y-axis scale, is between 6.5 and 14.5 mg/L. In examining this graph, you can not compare the magnitudes or sizes of the changes in water temperature and DO because they are measured in different units. However, you *can* compare the *directions* of the changes in these variables and the *timing* of when changes occur.

In the example shown in EA-EX-7 we can look at two types of change: those that occur over the year and those that occur over shorter periods of time, on the order of a week.

Change over the year: We can see the seasonal cycle in the surface water temperatures as we noted earlier. We also can see a seasonal cycle in the dissolved oxygen, but it is dramatically different. Figure EA-EX-7 shows that the relationship between these two variables is *inverse*. Whenever the surface water temperatures are high, the dissolved oxygen content is low. Conversely, whenever the surface water temperature is low the dissolved oxygen content is high.

Short-term changes on the order of a week: In looking at shorter-term changes, we must note whether the data we are comparing were taken at the same time and location and whether data were taken at the same interval (i.e. once a day, once a week, once a month…). We can best compare data that are taken at the same time and location. In EA-EX-7 the data seem to have been taken at the same time, at about one week intervals. The data were taken at the same location, as noted in the key for the figure. In this case we also know that the Hydrology protocol calls for the measurement of these two quantities at the hydrology study site at one week intervals.

Note: Sometimes it is not possible to have data from the same time and location. In that case the graphs may show data at different intervals and possibly taken from different locations. Before analyzing the data you need to determine whether the locations and times are too far apart to make a useful comparison of the data, or whether some analysis can be done. If you determine that you can go ahead with the analysis, you must keep the differences in the data in mind when drawing any conclusions.

Now we can compare the surface water temperature and the surface water dissolved oxygen measurements on the shorter time scale. On this scale, too, it seems that if surface water temperature decreases, the surface water DO increases. This is seen most clearly in early to mid-March, where there is a large decrease in the surface water temperature (from about 5˚ C to 1˚ C), at the same time as there is a large increase in the surface water DO (from 12.1 to 13.8 mg/L). Similar short-term variations can be seen in early June and mid-November. However, there are also times when this relationship is not as clear, such as in July and mid-September.

Having detected this interesting inverse relationship we should now ask: "Is the evidence convincing enough to indicate a strong relationship between surface water temperature and surface water dissolved oxygen?" If so, then we have somehow to explain the data that are *inconsistent* with this conclusion. (One possible explanation is that there are other processes at work that might affect the surface water dissolved oxygen.) If we think that there is not enough evidence to draw a conclusion, then we might want to determine what we would need to do in order to draw a conclusion. One possibility is to conduct a laboratory experiment in which we can control other variables and then measure dissolved oxygen and temperature in water as we change the temperature. We will then get another graph of temperature and dissolved oxygen and will have to determine if the data show a relationship and if there are any inconsistencies. If there are inconsistencies with the conclusions we draw, they will have to be explained in a scientific manner.

Reading a Graph with Multiple Variables

Looking at a graph with multiple variables, Figure EA-EX-8, is similar to looking at a graph with two variables, just more complex. First, we follow steps 1-5 in the section "Graph with One Variable" for each of the variables in this new graph. Then we look at the different scales involved in the graph. Instead of looking at two scales on the y-axis, as we did when considering two variables, we now have to consider scales for each of the variables represented and match the correct scale with the correct variable. Sometimes one scale may serve for more than one variable.

In Figure EA-EX-8 some compromises were made to make the data more readable. First, the temperature data are shown as a monthly average, while the rainfall and soil moisture data are shown as daily values. While this does eliminate the possibility of comparing daily variations in temperature to daily changes in precipitation and soil moisture, it makes the graph easier to read. Consider if the daily maximum temperature data shown in Figure EA-EX-5 were put in the graph in Figure EA-EX-8. The overlapping of the data would make it difficult to read. Therefore, the monthly average maximum air temperature has been plotted.

The second compromise is that the x-axis no longer covers a whole year. Again, this change is to facilitate reading the graph. The period of time shown is April to October 1998. This is the time of interest, when the soil moisture is falling and is more responsive to changes in precipitation. During the rest of the year, the soil moisture at Reynolds Jr. Sr. High School is pretty constant at about 27% (this was determined by first looking at graphs of these variables that covered all of 1998). The graph was changed to cover this shorter period to make the graph easier to read and therefore facilitate analysis and the eventual drawing of conclusions.

There are many interesting relationships to examine on this graph. One is the relation between soil moisture at 10 cm and precipitation events. If you look closely at the graph, you can see that once the soil moisture drops below its winter maximum value, every time there is precipitation the soil moisture at 10 cm increases temporarily. In addition, you can see that the precipitation event occurs before or right at the beginning of the increase in soil moisture at 10 cm. This would indicate that the precipitation event occurs first and provides the water necessary to increase the soil moisture. Once the rain stops, the soil moisture at 10 cm begins to decrease.

In *Learning Activity LC3* in this chapter, students can work with this graph and others that they create at the GLOBE Web site to further investigate the relationships among the different components of the Earth system at their study site and at the study sites of other GLOBE schools.

LC1: Connecting the Parts of the Study Site

Purpose

To help students articulate and integrate their existing knowledge about the air, water, soil, and living things by viewing them as interacting parts of a system

Overview

Students visit a study site, where they observe and recall their existing knowledge of air, water, soil, and living things to make a list of interconnections among the four Earth system components. They make predictions about the effects of a change in a system, inferring ways these changes affect the characteristics of other related components.

Student Outcomes

Students will be able to,

- identify the major components of the Earth system, and give examples from their local study site;
- infer connections among the atmosphere, hydrosphere, biosphere, and pedosphere by describing connections among examples at the study site; and
- predict some ways that changes in one component of the study site might affect the changes in other components.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Energy flows through ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers).

Organisms both cooperate and compete in ecosystems.

The population of an ecosystem is limited by its resources.

Humans can change ecosystem balance.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

The interaction of organisms in an ecosystem have evolved together over time.

Scientific Inquiry Abilities

Observing the Earth system

Sharing and comparing observations, predictions, and conclusions

Develop explanations and predictions using evidence.

Time

2-3 45-minute class periods

Level

Middle, Secondary

Materials and Tools

Pencils, pads of paper with stiff backing

Optional: magnifying glasses, trowels, gloves

Preparation

Select and visit a study site for Earth as a system.

Prepare students for a trip to study site.

Make copies of Learning Activity *Work Sheets*

Recording Interconnections

Effect of One Component on Another

Identifying Sources for Ideas

Understanding Earth System Concepts

Assessment rubrics for this activity (if you wish to share them with your students)

Crosswalks to Other GLOBE Learning Activities

All of the activities listed below reinforce the concept that components of the Earth system change each other through their interactions. This concept is central to an understanding of systems, and to this activity.

Hydrology Investigation: Water Walk

This activity helps students become familiar with the Earth's bodies of water and the differences in characteristics of water. Students learn that the characteristics of bodies of water are closely related to the characteristics of the surrounding land.

Hydrology Investigation: The pH Game

Students learn that the level of pH influences the vegetation and wildlife in a site, and is itself influenced by different factors in the rocks and soil, human activities, the atmosphere (precipitation), and amount of water in the landscape.

Hydrology Investigation: Macroinvertebrate Discovery

Students investigate the correlations between macroinvertebrates and the water chemistry where those animals live, learning that those two components of the Earth system are related.

Soil Investigation: Just Passing Through

Students develop an understanding of some of the relationships between water and soils of different types.

What To Do and How To Do It

Step 1. Select a Study Site for the Earth as a System.

The study site for this activity can be the same as the study site for the GLOBE *Hydrology Investigation*, but it does not have to be. Since the system includes air, water, soil, and living things the most appropriate site will have representations of all those components. A site adjacent to a canal, pond, or stream would be a good one. If such a body of water is not available, you can use any site where plants and any kind of animals are living under natural conditions.

Visit the Site.

You may wish to visit the site shortly before conducting the activity, to determine the best locations for class discussions and student field work. You'll also need to consider any other aspects of the site. (Is there poison ivy? Will it be wet underfoot? Will students need insect repellent?)

If you are planning to conduct the next activity, *Local Connections 2 (LC2)*:

Obtain One or More Photographs of the Study Site.

It is suggested that the teacher or one or more students assigned by the teacher take several photographs of the study site with one in each of the 4 cardinal directions (N, E, S, W). If this is done before beginning the learning activities, there will be time to have the film developed. The photographs should show as many as possible of the four major Earth system components. Students will use copies of the best photographs as a basis for making diagrams of interconnections in the *Activity LC2*. If the best photographs do not show all of the important features of the study site, you can instruct students to include it in their annotations and diagrams regardless. It is suggested that for the sake of simplicity in implementation, you not have students work with more than one photograph. Have exposed film and prints made as soon as possible.

If you do not plan to conduct the next activity, Activity LC2, you will still need to discuss students' lists of interconnections and the designations they gave them, to bring closure to their work. Refer to Steps 1-4 of *Activity LC2* to do this.

Step 2. Introduce the activity with a discussion of dramatic events or changes that have occurred in your local area.

Ask students to suggest events or changes, such as drought, flood, hurricane, fire, or loss of a particular habitat such as a wetland. Have students describe these events. What changed? What do people understand about it? What don't people understand? What do we still need to find out?

Explain that a new discipline of science – Earth system science has emerged, one in which people attempt to understand changes like these by learning more about ways that parts of the Earth interact to shape the environment. Earth system science integrates all sciences that are concerned with the Earth: geology, hydrology, chemistry, botany and zoology, and meteorology.

People who study the Earth as a system are pioneers in this new discipline, and, as experts on their own local areas, GLOBE students can participate in the pioneering effort. Every area, every site is unique in certain ways. Ask students: How would you apply Earth system science to one of your study sites? How would you communicate the *system* aspect of your study site, its parts and how they interact, to another GLOBE school?

Explain that each one of the activities in the *Local Connections (LC)* series addresses aspects of this question.

Step 3. Describe the study site briefly for students if they're unfamiliar with it, and ask them how they might describe it as a set of parts, or components.

Tell students that in this activity, they will begin to consider how their study site is a system, a set of parts that interact with each other.

If students were to describe their study site (or any site) as a set of parts, or components what would the components be?

Step 4. Help students identify in the study site the four major components that make up the Earth system.

First help students identify these four major components:

1. air (atmosphere) — including precipitation and clouds;
2. water (hydrosphere) — bodies of water such as canals, streams, ponds, lakes, and oceans, as well as groundwater;
3. soil (pedosphere);
4. living things (biosphere) — plants, animals, and other organisms.

Explain that these are the parts, or components, of the study site. Ask students to describe some of the processes that connect them. If students have already learned about the water cycle, the chemical cycle, and the energy cycle, these can be recalled.

Now advise your students that they are going to investigate their study site in terms of these four components and how they connect with each other. Tell them they will make lists of these interconnections. For example, plant parts decay and become part of the soil (an interaction between living things, water, soil and air); water is evaporated from oceans and forms clouds (an interaction between water and air). Ask students to suggest a few examples from one of their GLOBE study sites.

Explain that a change in the characteristics of one of the four components of a system usually results in changes in the characteristics of the other components of the system. For example, if the amount of water in a stream is reduced (water component, or hydrosphere), less erosion occurs (soil component, or pedosphere); less water is available for plant and animal growth (living things component, or biosphere); and less water is available for evaporation (air component, or atmosphere).

Let students know that they are not all required to develop the same lists of interconnections. Different lists will probably reflect different emphases on areas that are of special interest or experience.

Make it clear to students that they do not have to be able to see the interactions to put them on the list. Some of the interactions are ones they will be able to observe while at the study site; others they may remember from collecting GLOBE data, or from another science experience.

Some students may wonder why precipitation is included in the air component, rather than in water. The reason is that water in the air (evaporated water and precipitation) is affected by winds and other forces in the atmosphere, until it has fallen again to Earth.

Make sure students are equipped with pencils and pads of paper for making lists before leaving for the study site.

Step 5. Distribute the Learning Activity Work Sheet *Recording Interconnections,* **take students to the study site, and have them make lists of interconnections among components.**

The interconnections should be listed as phrases or short sentences such as, "Water evaporates from the stream," or "Heat from the soil warms the air."

Encourage students to explore actively if it will help them think. They can dig small holes, turn over stones, and examine the water, soil, and vegetation with a magnifying glass. They can take time to sit quietly and contemplate the study site as well.

Encourage students to articulate and note as many of their thoughts and ideas as they can. The point of this activity is for students to,

1. recall and articulate their existing knowledge; and
2. think creatively about ecological processes that may take place at the study site.

Creative thinking and speculation based on sound scientific information are among the keys to scientific work. In the homework assignment, students will be asked to evaluate the sources of their ideas about interconnections, in terms of whether they are based on informed speculation, background knowledge, or data.

Instruct your students to consider only the components within the study site. In other words, they should not include the sun itself as part of the study site for this activity, because it is the sun's energy that enters the site, not the sun itself. However, knowing that the study site receives heat energy from the sun, they should include heat, as it is transported among study site components. (For example, the soil, warmed by energy from the sun, in turn warms the air above it, a pedosphere - atmosphere interconnection.)

Instruct students to focus on interconnections among the four basic Earth system components, rather than within one of them. For example, a student may want to list one interconnection as insects (living things) consuming plants (living things). Both insects and plants are living things, and so are part of the biosphere, and while insects do indeed consume plants, this is a process that occurs within one component, not between components. An example of an interconnection between components is insects taking oxygen from the air, an interaction that occurs between the biosphere and the atmosphere.

For each interconnection, students should identify the Earth system components that are involved.

Students may ask others what they are looking at and thinking about. Making lists of interconnections can be a cooperative effort.

Students may include photosynthesis in their diagrams. In photosynthesis, plants use energy from sunlight to change carbon dioxide and water into food. So, although the sun itself is outside the boundary of the study site system, photosynthesis can be considered a biosphere – atmosphere interaction.

Advanced students' lists of interconnections will be more sophisticated and complex than middle students' lists. Whatever the students may have learned about the water cycle, the energy cycle, and the biogeochemical cycle can be applied here.

If students need prompting, refer to *Questions about Interconnections Among Components of an Earth System,* in the Teacher Guidelines on the next page.

A *Sample Student List of Interconnections* is also provided.

Step 6. In the classroom, have students discuss and predict the possible effects of changes at the study site.

Upon returning to the classroom, distribute the Learning Activity Work Sheet *Effect of One Component on Another*. Have students speculate about how selected changes might affect the study site. Material is provided on the next page to help you work with students on two possible changes: a rain storm and a dramatic rise in temperature.

Have students focus on effects of interconnections among the four major Earth system components (air, water, soil, and living things). What is important here is for students to realize that a *change in one component of the system can affect the characteristics of other components.* You may choose to have students do this now, or as a homework assignment. If the latter, conduct a class discussion about their predictions during the next class period, after the homework is turned in.

Advanced students can generate their own questions and predictions about ways that changes in one component will affect others.

For tips on helping your students, see Teacher Guidelines, *Questions About Interconnections Among Components of an Earth System, Sample Student List of Interconnections,* and *Effects of One Component on Another.*

Step 7: Assign homework.

Two homework assignments, Learning Activity Work Sheets *Identifying Sources for Ideas* and *Understanding Earth System Concepts,* are provided. Distribute copies to students.

The homework assignment *Identifying Sources for Ideas* is intended to help students learn to clarify the sources of their ideas: whether they are based on "hard" data, background information, or scientifically informed speculation. Students are to review their lists of interconnections at home and assign one of the designations that follow to *each* interconnection on the list:

D – To designate an interconnection for which they have data, whether GLOBE student measurements or data obtained by others;

B – To designate an interconnection that they recall from their own backgrounds, i.e. from previous reading or from experience in another course, that they actually could find and bring to class, given enough time;

S – To designate an interconnection that is scientifically informed speculation.

Tell the students that these designations are described on the work sheet. Make sure that they take home the lists of interconnections that they developed during this activity.

The homework assignment *Understanding Earth System Concepts* is a student self-reflection log. Students are asked to write about what they are learning, what may be confusing them, and what they would like to learn more about.

If you plan to conduct the next activity, Activity LC2, go to Step 8.

Step 8. Wrap up this activity.

Explain to students that during the next activity they will discuss their lists of interconnections, and they will begin making diagrams of the study site. Explain that student lists of interconnections will be collected for assessment after the next activity and returned to them later.

If students wrote in class about predictions of changes to the study site, those should also be collected for assessment.

Student Assessment

Four *Work Sheets* can be used for assessment:

- *Recording Interconnections*
- *Effect of One Component on Another*
- Homework Assignments-*Identifying Sources for Ideas, Understanding Earth System Concepts*

Concepts and skills that students display during this activity will be further developed if you plan to conduct *Activities LC2* through *LC5*. Assessment at this early stage will provide benchmarks against which to measure student progress later on.

Rubrics for assessment of the first two work sheets and the homework assignment, *Identifying Sources for Ideas* are provided. Homework Assignment, *Understanding Earth System Concepts* is a self- assessment. Student self-reflection logs play a special role, as students may be more comfortable describing confusion they feel or other problems they're having that they would not feel free to bring up with the whole class. You can use this information to help shape the next stage of your teaching with these activities.

Further Investigations

Earth System Component Chemistry

It has been said that each Earth system component — atmosphere, hydrosphere, pedosphere, and biosphere — is made of the others, in varying percentages. In other words, the air contains water, soil, and living things; the soil contains air, water, and living things; the water contains air, soil, and living things; and living things contain air, water, and parts of the soil. Discuss with students. Is this true? How or how not?

Teacher Guidelines

Questions about Interconnections Among Components of an Earth System

If students need prompting, you can ask them questions such as these.

Atmosphere–Hydrosphere Interconnection

- How does the presence of a stream, pond, lake, or ocean affect the air temperature nearby? (hydrosphere – atmosphere)
- How does a rainstorm affect rivers and streams?

Atmosphere–Lithosphere (Pedosphere) Interconnection

- Does the amount of moisture in the soil change? How? (atmosphere – pedosphere)
- How does the presence of large areas of rocks or asphalt affect the air temperature nearby? (Rocks are part of the lithosphere which is distinct from the soil, which is the pedosphere. Asphalt is man-made but is made up of natural materials. You can call this lithosphere – atmosphere interaction or more simply surface – atmosphere interaction)

Atmosphere–Biosphere Interconnection

- What do plants, animals, and other organisms obtain from the air? What is transported from each of those groups of organisms into the air? (biosphere –atmosphere)
- Where does heat in the soil and in the air come from? Did you know that the sun mainly warms the air only indirectly? (The soil is warmed by the sun, which heats the air, and not the other way around.) (pedosphere – atmosphere)

Hydrosphere–Lithosphere Interconnection

- Is moisture present in the soil? How does it get there? (hydrosphere – pedosphere)

Hydrosphere–Biosphere Interconnection

- How does water get from the stream (or pond, lake, canal, or ocean) to the trees? (hydrosphere – biosphere)
- How does the presence of a stream (or pond, lake, canal, or ocean) affect plants and animals? What are differences among species that live in it, species that live adjacent to it, and species that live 20 meters or more away from it? (hydrosphere – biosphere)

Biosphere–Lithosphere (Pedosphere) Interconnection

- How do leaves become part of the soil? (biosphere – pedosphere)
- Does water carry soil? When and how? (biosphere – pedosphere)
- How do plants affect the soil? (biosphere – pedosphere)
- How do animals affect the soil? Remember, there are animals living in the soil as well as on its surface. (biosphere – pedosphere)
- How do bacteria and other microorganisms affect the soil? How are they affected by the soil? (biosphere – pedosphere)

Sample Student List of Interconnections

Atmosphere–Hydrosphere Interconnection

- Water evaporates from the stream into the air. (hydrosphere – atmosphere)
- Gases move between the atmosphere and the water.
- Rain and snow from the atmosphere goes into the surface water.

Atmosphere–Lithosphere (Pedosphere) Interconnection

- Rain and snow from the atmosphere goes into the soil.
- Gases from volcanoes go into the atmosphere.

Atmosphere–Biosphere Interconnection

- Animals inhale oxygen from the air, and exhale carbon dioxide. (biosphere – atmosphere)
- Plants take in carbon dioxide and let out oxygen. (biosphere – atmosphere)
- Microorganisms take some gases from the air, and some gases are transported from

microorganisms to the air. For example, some bacteria take nitrogen from the air. (biosphere – atmosphere)
- Aquatic animals breathe dissolved oxygen in the water. (biosphere – atmosphere)
- Heat from the surface warms the air. (pedosphere – atmosphere)
- Heat in the air warms animals, plants, and microorganisms. (atmosphere – biosphere)
- The amount of water in the site helps determine which species of plants and animals live there. (hydrosphere – biosphere

Hydrosphere–Lithosphere (Pedosphere) Interconnection

- Rain and snow drop water onto the ground. Some of it flows away, and some of it seeps into the ground. (hydrosphere – pedosphere)
- Earthworms consume parts of the soil. (biosphere – pedosphere)
- Rain wears away little bits of rock. These become part of the soil. (hydrosphere – lithosphere – pedosphere)
- Rain beats down on soil near the stream, and some of it carries soil away (erosion). (pedosphere – hydrosphere)

Hydrosphere–Biosphere Interconnection

- Trees take in water through their roots. (biosphere – hydrosphere)
- Water evaporates from leaves of trees and other plants. (biosphere – hydrosphere)
- Animals breathe out some water. (biosphere – hydrosphere)
- Animals drink water. (biosphere – hydrosphere)

Biosphere–Lithosphere (Pedosphere) Interconnection

- Waves wear away pieces of shells and break shells up into bits. These become part of the soil (sand). (biosphere – pedosphere)
- Soil erosion makes the water more turbid, which reduces the depth to which sunlight can penetrate the water. This diminishes the ability of plants to carry out photosynthesis, thus affecting their ability to grow. (pedosphere – biosphere)
- Plants take nutrients from the soil. When they die, they put nutrients into the soil. (biosphere – pedosphere)

Effects of One Component on Another

Select two or more of these questions, ask students to make predictions, and discuss the predictions as a class.

Change No. 1: Rain storm

Guiding Questions

- How would a change in water level affect plants and animals at the site?

  (The amount of available water is a determining factor in which species of plants, animals, and microorganisms can live at a given place.)
- How might heavy precipitation affect soil moisture levels?

  (Soil moisture levels will rise following heavy precipitation. Once the soil is saturated, remaining moisture will not be absorbed, but will run off the site.)
- How might the storm affect erosion?

  (The impact of rain drops and runoff cause soil erosion where vegetation does not protect the soil.)
- What happens to the flow of water in a stream or river during rain storms? What effects might that have on plants and animals in the water? What effects might it have on the soil at the bottom of the stream (or pond, lake, canal, or ocean)?

  (The flow of water increases during rain storms. If a storm drops a lot of water on the site, the flow will be great, and may cause physical distress to plants and animals in the water, possibly even removing them from the site. It will disturb sediments at the bottom of a stream, which will cause turbidity to increase, lowering the rate of plant photosynthesis.)

- If rain storms are frequent and regular at the study site over a number of years, how might that affect interconnections among components?

  (Such rain storms will scour the bottom of a stream or canal, and plants or seeds living near it may be removed. Soil throughout the site will be saturated, and species of plants, animals, and microorganisms that cannot tolerate saturated soil will be replaced by species that can tolerate it. Temperatures overall may change, and that too may affect which species live at the study site.)
- How might long periods with large amounts of cloud cover affect vegetation?

  (Temperatures may change, and the rate of photosynthesis will decrease. Plant and animal species that require long hours of full sun will be replaced by species that flourish with less sunlight.)

Change No. 2: Dramatic Rise in Temperature

Guiding Questions

- What would happen to the components at the study site if the temperature rose dramatically for an extended period, in a prolonged heat wave?
- What changes in evaporation rates could be expected?
- How might that affect the soil?
- How might it affect living things?
- How might it affect the water?

  (Evaporation rates would increase, resulting in a drier site, although this could be complicated by changes in precipitation. Plant, animal, and microorganism species that could not tolerate higher temperatures would be replaced by species that could. If there were few plants that could tolerate the higher temperatures, the soil might become exposed, and soil erosion by both wind and water would increase. The hydrologic cycle would become more vigorous, meaning that there would be more evaporation and more precipitation, and therefore more water moving through the cycle faster.)

Recording Interconnections

Work Sheet-1

Name:________________________________ Class: ______________________Date:___________

Instructions

Look around your study site. Analyze and describe it in this way:

1. Identify some examples of the four major components: living things, water, soil, and air. (Air includes hot and cold air, wind, clouds, and precipitation.) (The components are also known as: biosphere, hydrosphere, pedosphere, and atmosphere.)
2. Identify and record connections among these components by: making observations; recalling and integrating your existing knowledge about them; and speculating carefully about the connections that might be taking place.

Record answers on next page or on a separate piece of paper, and attach it to this *Work Sheet.*

Tips, Questions, and Comments to Get You Thinking

- Write down your observations as short phrases. *Use verbs.* Example: Leaves fall, decompose, and become part of the soil.
- Write down as many interconnections as you can think of. Be as specific as you can. You can even use general quantities, such as “a little,” “some,” or “a lot”.
- Work with other students if you wish. But before you add anything to your list, make sure you understand it *and agree with it!*
- Examples of questions you might consider:

  What happens in the soil that changes the characteristics of the living things at the site? What happens in the water that changes the characteristics of the air?

  What moves from one study site component to the other?
- It may help your thinking to compare this place to others. What’s happening at this site that doesn’t happen somewhere else? How is this one different? What about soil characteristics? Different kinds of plants? Less water, or more?
- Recall ideas from other courses you have taken. Think about biology, chemistry, Earth science, ecology, geography, meteorology, and physics.
- After you’ve made an initial list, look it over. *Be sure you have described examples at the study site for each of the 4 components.* Is each of them acting upon *each* of the other three in at least two or three ways?

An excellent list of interconnections will be long; it will involve all of the components; it will be specific; it will bring in your knowledge from previous studies in other classes as well as this one; and it will show that you are thinking deeply and carefully about your study site.

Examples of Four Major Components

Atmosphere	*Hydrosphere*
Pedosphere	*Biosphere*

Connections Among Components

Atmosphere–Hydrosphere Interconnection	**Atmosphere–Lithosphere (Pedosphere) Interconnection**
Atmosphere–Biosphere Interconnection	**Hydrosphere–Lithosphere Interconnection**
Hydrosphere–Biosphere Interconnection	**Biosphere–Lithosphere(Pedosphere) Interconnection**

Effects of One Component on Another

Work Sheet-2

Name:________________________________ Class: _______________________Date:___________

Instructions

Choose three or more of the questions below, and on the back of this sheet or on a separate piece of paper, describe your predictions of ways that a change in the characteristics of one component of the study site might affect the characteristics of other components.

Be as specific as you can. For example, if someone planted a tree at the site, the ground beneath it would be shaded; the temperature of that soil would decrease, and the soil moisture level would increase.

It is not necessary to respond to all of these questions. **What is important here is for you to demonstrate your understanding of how a change in the characteristics of one component of the study site may result in changes to the characteristics of other components.** All aspects of the site are connected.

Indicate on this sheet which questions you are addressing, and attach your responses to the questions to this page before turning it in.

Change No. 1: Rain Storm

- How would a change in water level affect plants and animals at the site?
- How might heavy precipitation affect soil moisture levels?
- How might the storm affect erosion?
- What happens to the flow of water in a stream or river during rain storms? What effects might that have on plants and animals in the water? What effects might it have on the soil at the bottom of the stream (or pond, lake, canal, or ocean)?
- If rain storms are frequent and regular at the study site over a number of years, how might that affect interconnections among components?
- How might long periods with large amounts of cloud cover affect vegetation?

Change No. 2: Dramatic Rise in Temperature

- What would happen to the components at the study site if the temperature rose dramatically for an extended period, in a prolonged heat wave?
- What changes in evaporation rates could be expected?
- How might that affect the soil?
- How might it affect living things?
- How might it affect the water?

Ask Your Own Questions

Ask some of your own questions about changes here, and predict the effects of those changes to other components of the study site. Your questions can have to do with any aspects of the study site, not just rain storm events or climate. Ask yourself, "What if…?" and take it from there. For example:

- What if no birds flew into the study site?
- What if twice as many birds flew into the study site as do now?
- What if no people ever came again?

Identifying Sources for Ideas

Work Sheet-3:
Homework Assignment

Name:________________________________ Class: _______________________Date:___________

Assignment 1

For each interconnection on the list you made during this activity, identify what kind of source you used for the idea. (See below.)

Review your list of interconnections. Make any additions or changes that you wish. Make sure you have involved and correctly identified the four major components of the study site as a system: atmosphere (air and precipitation), hydrosphere (water), biosphere (living things), and pedosphere (soil).

Now review the list again, with particular consideration for where you got your ideas. Write one of the designations below next to *each* interconnection on the list:

D – Your concept is based on data. Use "D" to designate an interconnection for which you have or have seen data, whether it is data collected by your class, another GLOBE school, or others

B – Your source is background information. Use "B" to designate an interconnection that you have recalled from previous reading or experience in another course, at home, or elsewhere, and that you could actually find and bring to class, given enough time. There may be data somewhere to substantiate this, but you either have not seen it or you do not have easy access to it.

S – Your source is speculation. Use "S" to designate an interconnection that is scientifically informed speculation on your part. This is your opinion based on what you have learned over time but you can not point to a particular source of data or other information to support it. (Creative speculation — when based on authoritative background information and data — is one of the keys to excellent scientific work.)

As you write the letter designation (D, B, or S), put a small circle around it, so that it will be clear and legible to others.

Understanding Earth System Concepts

Work Sheet-4:
Homework Assignment

Name:______________________________ Class: _____________________Date:__________

Assignment 2

Take a few minutes to consider and write about what you are learning. If you need more space use the back of this paper, or attach additional sheets.

1. Give several examples of connections you detected in this activity. What are you confident about? What are you confused about? Are you stuck anywhere?

2. Were you able to identify examples of the Earth system components at your study site? What did you learn? What are you confused about? Please explain.

3. Were you able to predict changes in the study site? Did you understand what was being discussed? Please explain.

4. Do you see that a change in the characteristics of one of the system components usually results in changes in the characteristics of the other components? Would you be able to give examples of this readily if someone asked you? Give examples.

Assessment Rubric: *LC1: Connecting the Parts of the Study Site*

Recording Interconnections Among Components of the Study Site

	4	3	2	1
Study Site Components Included	Includes and correctly identifies all 4 major components	Includes and correctly identifies 3 major components	Includes and correctly identifies 2 major components	Incompletely and/or incorrectly includes and identifies major components
Interconnections Proposed	Specifically describes 4 or more scientifically appropriate inter-connections for each component of site	Describes 3 scientifically appropriate intercon-nections for each component of site	Describes 2 or fewer interconnections for each component of site; some are not scientifically appropriate	Describes no scientifically appropriate interconnections
Clarity of Descriptions	Uses short phrases with verbs to indicate inter-connections, and writes very clearly	Uses short phrases with verbs to indicate inter-connections; most are written clearly	Uses unclear phrases to indicate most inter-connections	Uses unintelligible phrases

Assessment Rubric: *LC1: Connecting the Parts of the Study Site*

Predicting Ways that a Change in the Characteristics of One Component of the Study Site May Affect the Characteristics of Other Components

	4	3	2	1
Predictions Made questions	Responds to 3 or more questions, generates 2 or more new questions	Responds to 2 questions, generates 1 new question	Responds to 1 or 2 questions, does not generate any new	Does not respond to questions; does not generate any new questions
Predictions Based on Sound Scientific Principles	Bases all predictions on sound scientific principles; shows careful thought about interconnectedness of system components	Bases most predictions on sound scientific principles; shows some thought about interconnectedness of system components	Bases predictions on questionable concepts; shows little thought about interconnectedness of system components	Makes no predictions; reflects little thought about interconnectedness of system components

Assessment Rubric: *LC1: Connecting the Parts of the Study Site*

Designating Information Sources for Interconnections

	4	3	2	1
Information Source Designations (D, B, S)	Identifies all information sources accurately and thoughtfully thoughtfully	Identifies most information sources accurately and thoughtfully	Identifies some information sources accurately and or thoughtfully	Identifies few or no information sources accurately

LC2: Representing the Study Site in a Diagram

Purpose

For students to learn the skills and value of translating complex interactions among Earth system components into a simplified diagram

Overview

Students develop their ability to understand and draw a diagram of their study site as a system of interconnected components. Beginning with photographs of their study site, students label Earth system components and interconnections, and then produce a simplified diagram of the site. After sharing and discussing the labels and relationships on their diagrams, students further revise their drawings.

Student Outcomes

Students will be able to:

- Analyze a photograph of their study site with respect to Earth systems;
- Annotate interconnections among Earth system components on a photograph;
- Translate their analysis of the study site into a diagram of the site;
- Produce a simplified diagram of the site;
- Interpret, evaluate, and constructively criticize the diagrams of other students.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Communicating science concepts through diagramming

Evaluating diagrams of other students

Presenting evidence to support ideas and justify decisions

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

90 minutes (Two class periods)

Level

Middle, Secondary

Materials and Tools

One copy of your study site photograph for each student, (*or* copy Figure EA-LC2-1)

List of interconnections from *Activity LC1*, either your students' own or the sample list

Preparation

Select a study site (if you didn't do *LC1*).

Create or obtain one or more photographs of the study site.

Read *Diagramming Earth as a System.*

Make student copies.

Prerequisites

None

Special Notes

About Diagramming

As explained in *Diagramming Earth as a System*, students progress from literal diagrams to more symbolic and abstract representations. This progression can be described as a set of four phases (only the first three phases are required in this activity. The fourth phase is optional, for advanced students):

Phase 1. Photograph with annotations (sentences or phrases with verbs)

Phase 2. Literal diagram of the site based on the photograph; phrases used in Phase 1 retained (and perhaps embellished)

Phase 3. Simplified diagram; verbs replaced with arrows

Phase 4. Abstract representation where symbols and color and size keys are used for all representations

A separate student product culminates from the first three phases in this activity. The Phase 3 diagram will be used in *Activity LC4*.

Advanced students are capable of greater degrees of abstraction, and should be able to develop a completely abstract diagram with arrows. The teacher can gauge the degree of abstraction that each class (or individual student) is capable of, and shape this activity accordingly.

The completely abstract diagram is suggested as an optional student product.

About Posting a List of Interconnections on the Board (See Step 4.)

If you leave the list of interconnections on the board for an extended time during and after this activity, students will have more opportunities to absorb the information and to reflect on how it applies to their diagrams of the study site.

It will be important for students to have time to revise and refine their diagrams. It may be appropriate for some students to do revisions as a homework assignment.

What To Do and How To Do It

Step 1. Preparation

Select a Study Site

If you did not conduct Activity LC1, you will need to select a study site. It can be the same as the study site for the GLOBE *Hydrology Investigation*. It should be one that is familiar to students. The most appropriate site will have representations of water, soil, air, and living things. A site adjacent to a canal, pond, or stream would be a good one. If such a body of water is not available, you can use any site where plants and animals (of any type) are living under natural conditions.

Obtain a Photograph of the Study Site

If you did not conduct *Activity LC1*, take photographs of the study site now. Select one photo that shows all the major features of the study site, and copy it for students. Copies of black-and-white prints will work. You may choose to make overhead transparencies of some photographs, to support classroom discussions.

Read

Diagramming Earth as a System in the Introductory section of *Exploring the Connections* in the *Earth as a System* chapter of the *GLOBE Teachers Guide*, if you have not done so already. It will provide guidance as you help your students with their diagramming. You may choose to make copies of this for your students also.

Make Student Copies

Guidance for Students
- *Annotating a Study Site Photograph*
- *Diagramming Your Study Site*

Work Sheets:
- *Student Self-reflection Log: The Study Site as a System*
- *Student Self-reflection Log: What Have You Learned from Diagramming Your Study Site?*

Assessment rubrics for this activity (You may want to share with students.)

In addition, if you have not conducted *Activity LC1*, make student copies from that activity of:

Sample Student List of Interconnections;

Figure EA-LC2-1, Photographs of Reynolds Jr. Sr. High School study site.

Step 2. *(If you did not conduct the Activity LC1)* **Introduce the activity with a discussion of dramatic events or changes that have occurred in your local area.**

Ask students to suggest events or changes, such as drought, flood, hurricane, fire, or loss of a particular habitat such as a wetland. Have students describe these events. What changed? What do people understand about it? What don't people understand? What do we still need to find out?

Explain that a new discipline of science – Earth System Science has emerged, one in which people attempt to understand changes like these by learning more about ways that parts of the Earth interact to shape the environment. Earth system science integrates all sciences that are concerned with the Earth: geology, hydrology, chemistry, botany and zoology, and meteorology.

People who study the Earth as a system are pioneers in this new discipline, and, as experts on their own local areas, GLOBE students can participate. Every area, every site is unique in certain ways. Ask students: How would you apply Earth system science to one of your study sites? How would you communicate the *system* aspect of your study site – its parts and how they interact – to students at another GLOBE school?

Explain that each one of the activities in the *Local Connections* (*LC*) series addresses aspects of this question.

Step 3: Help students identify four major components of the study site as an Earth system (or, if you conducted *Activity LC1*, remind them):

Air
Water
Soil
Living things

(If you did not conduct *Activity LC1*, during which students visit their own study site, distribute copies of the Figure EA-LC2-1.)

Explain that scientists use the terms atmosphere, hydrosphere, pedosphere, and biosphere when referring to these components. The terms correlate with the titles of GLOBE investigations: *Atmosphere, Hydrology, Soil,* and *Land Cover/ Biology.*

Write these terms across the top of the board, making column headings under which specific interconnections will be listed.

Step 4. Using your students' lists of interconnections from *Activity LC1* **(if you conducted it), or the Sample Student List of Interconnections from** *Activity LC1,* **have the class determine which of the four major Earth system components are involved in each interconnection.**

Distribute the list of interconnections, or have students retrieve their own lists (which should include their homework from *Activity LC1*). Ask volunteers to describe some of the interconnections, and have the class determine which of the 4 major study site components are involved with each. The teacher or a selected student can list the interconnection on the board under the appropriate component headings. There should be two components involved in each interconnection.

If you conducted Activity LC1, continue with Step 5. If you did not conduct Activity LC1, go directly to Step 6.

Step 5. Once at least two or three interconnections for each component have been listed, discuss students' designations of each interconnection as being based on data (D), background information (B), or scientifically informed speculation (S), as described in *Activity LC1.*

Students should have written these designations next to each of the interconnections on their own lists, as homework. Go through this designation exercise as a class, with those interconnections already written on the board. Ask students to share their designations, and make sure that students can justify the designations they have used.

Some designations may be controversial, which can stimulate a lively discussion about the validity of different information sources.

Step 6. Have students share and discuss these and any other interconnections that occur to them.

Allow students to modify their own lists if they made them in *Activity LC1.*

Require students to justify their ideas on the basis of data or authoritative background information that they would be able to produce, given enough time. Creative speculation should be encouraged, as long as it is based on sound scientific information. Encourage discussion of controversial ideas.

Step 7. Remind students that they are dealing with the study site as a system.

Explain to students that they will be using what they have learned about the parts and interconnections of their study site to make a diagram of the site. This will result in a product that represents their site which they may share with students at other schools. A helpful first step toward this diagramming is to make notes on, or *annotate*, a photograph of the study site.

Step 8. Have students annotate their copies of the study site photograph.

Distribute copies of the photograph you have selected to show the study site, and copies of the Student Work Sheet, *Annotating a Study Site Photograph.* Ask students to annotate their copies in the following way:

1. Label the four major components.

2. Add short descriptions of the interconnections among them, using verbs in phrases or short sentences.

These will be "Phase One" annotated photographs, as described in *About Diagramming* in Special Notes, above.

If you need to use more than one photograph of the study site to capture all of the important features of the system, you can show it to students, but they should use only one image of the site for their annotations.

If there is not enough space for annotations on the photograph, students can attach it to a piece of paper.

Although instructions for students appear on their work sheets, you may wish to write instructions on an overhead transparency or on the board as well. Make sure students understand that their annotations are to show *connections* or *relationships* between components of the system, just as their lists of interconnections have done.

If a student represents an interconnection as going only one way, can she or he think of how it might also go the other way?

See Figure EA-LC2-2 for an example of an annotated photograph.

Advanced students may be capable of skipping Step 10, going directly from Step 9 to Step 11.

Step 9. (Optional) **Have students write a short reflection on their own learning.**

If this kind of work is new to some of your students, you may want to take five or ten minutes to make sure they have understood everything so far. Distribute the *Work Sheet, The Study Site as a System: Student Self-reflection Log*. Collect what they write, and review it while students are engaged in the next step of the activity.

Step 10. Now have students make a diagram of the study site, using their annotated photographs as guides.

These will be "Phase Two" diagrams, as described in *About Diagramming* in Special Notes above. Distribute copies of the *Diagramming Your Study Site (Literal Diagram): Work Sheet–3* for students to read as guidance in creating a simplified diagram.

Explain to students that they should simplify what appears in the photograph, but their diagrams should represent everything in the photograph. Let students know that a little later in the activity they will have opportunities to simplify their diagrams.

Students who are uncomfortable with drawing can use simple shapes to represent elements of the study site. Make it clear that this is not a drawing competition!

Students should annotate their diagrams with the same phrases or sentences they used on their annotated copies of the photograph, and they should retain the designations of the sources of their information (D, B, or S, for data, background information, or scientifically informed speculation). Encourage them to add new interconnections if more have occurred to them. They should make all annotations simple and clear.

Let students know that they can include people in their diagrams!

See Figure EA-LC2-3 for an example of an annotated literal diagram.

Step 11. Have students make simplified diagrams.

These will be "Phase Three" diagrams, as described in *About Diagramming* in Special Notes above. Distribute copies of the *Diagramming Your Study Site-Simplified Diagram Work Sheet-4* for students to read as guidance in creating a simplified diagram.

Instruct students to use arrows to represent the verbs they used in their annotated photographs and literal diagrams. They should draw one-headed arrows to indicate the directions in which the interactions are occurring, showing only one direction on each arrow.

Instead of drawing lots of trees, students can draw two or three. Instead of drawing a multitude of raindrops, they can draw one raindrop, or a small cluster. Instead of a sky full of clouds, they can draw one cloud.

As students simplify their diagrams, they will make decisions about what is most important to keep. This means they will make decisions about the essential elements of an Earth system.

Be sure to check students' work partway through this step. Particularly if diagramming is a new process for them, they may need guidance and feedback.

See Figure EA-LC2-4 for an example of an annotated simplified diagram.

Step 12. Have students share their diagrams in pairs.

Students in pairs should interpret and describe each other's diagrams. The student who made the diagram can listen and discover what s/he has communicated clearly and what s/he needs to improve on.

Encourage students to evaluate their partners' diagrams carefully, to ask questions about aspects that are unclear, and to offer only criticism that is constructive. Tell the class that they will be evaluated on the degree to which their comments on each other's work are positive and contribute to learning.

Suggest that students make notes on the characteristics of effective diagrams.

Step 13. (Optional, use for Advanced Level Students) **Have students develop abstract versions of their diagrams.**

These will be "Phase 4" diagrams, as described in *About Diagramming* in Special Notes above.

Instruct students to:

1. Use symbols for the interconnections in their simplified diagrams (made in Step 11); and
2. Retain their arrows to show interconnections.

Step 14. (Optional) **Ask students to complete another self-reflection log.**

Distribute *Student Self-reflection Log: What Have You Learned from Diagramming Your Study Site?: Work Sheet-5,* and ask students to complete it.

Step 15. If you plan to conduct *Activity LC3,* **prepare students for it.**

Tell students that interconnections among Earth system components can be explored mathematically, in graphs, as well as visually, in diagrams. Let them know that in the next activity, they will make graphs of GLOBE data, and will find out what can be learned through that medium about interconnections.

Step 16. Collect annotated photographs, student lists of interconnections, and diagrams for assessment.

If you plan to conduct *Activity LC4, Diagramming the Study Site for Others,* note that students' diagrams will be needed for that activity.

Student Assessment

These student products can be used for assessment:

Annotated photographs ("Phase 1" of diagramming)
Literal diagram ("Phase 2" of diagramming)
Simplified diagram ("Phase 3" of diagramming)
Students' interpersonal and communication skills when they receive and give feedback on the diagrams of others
Student Self-reflection Log: The Study Site as a System
Student Self-reflection Log: What Have You Learned from Diagramming Your Study Site?

Rubrics are provided for assessment of the annotated photographs, diagrams, and student interpersonal and communication skills when receiving and giving feedback are provided.

Though what students write on self-reflection is not assessed in quantifiable terms, the logs play an important role, and can be used to help shape the next stage of teaching.

Further Investigations

Familiar Systems

Ask students to name some systems. If they need prompting, suggest sports teams, groups of friends, car engines, etc. Ask students to identify the parts, or components, of each system, and ways those components interconnect. Ask students to sketch a diagram of any system they choose.

Figure EA-LC2-1: Photograph of Reynolds Jr. High School Study Site in Greenville, Pennsylvania USA

Figure EA-LC2-2: Annotated Photograph of Study Site at Reynolds Jr. Sr. High School

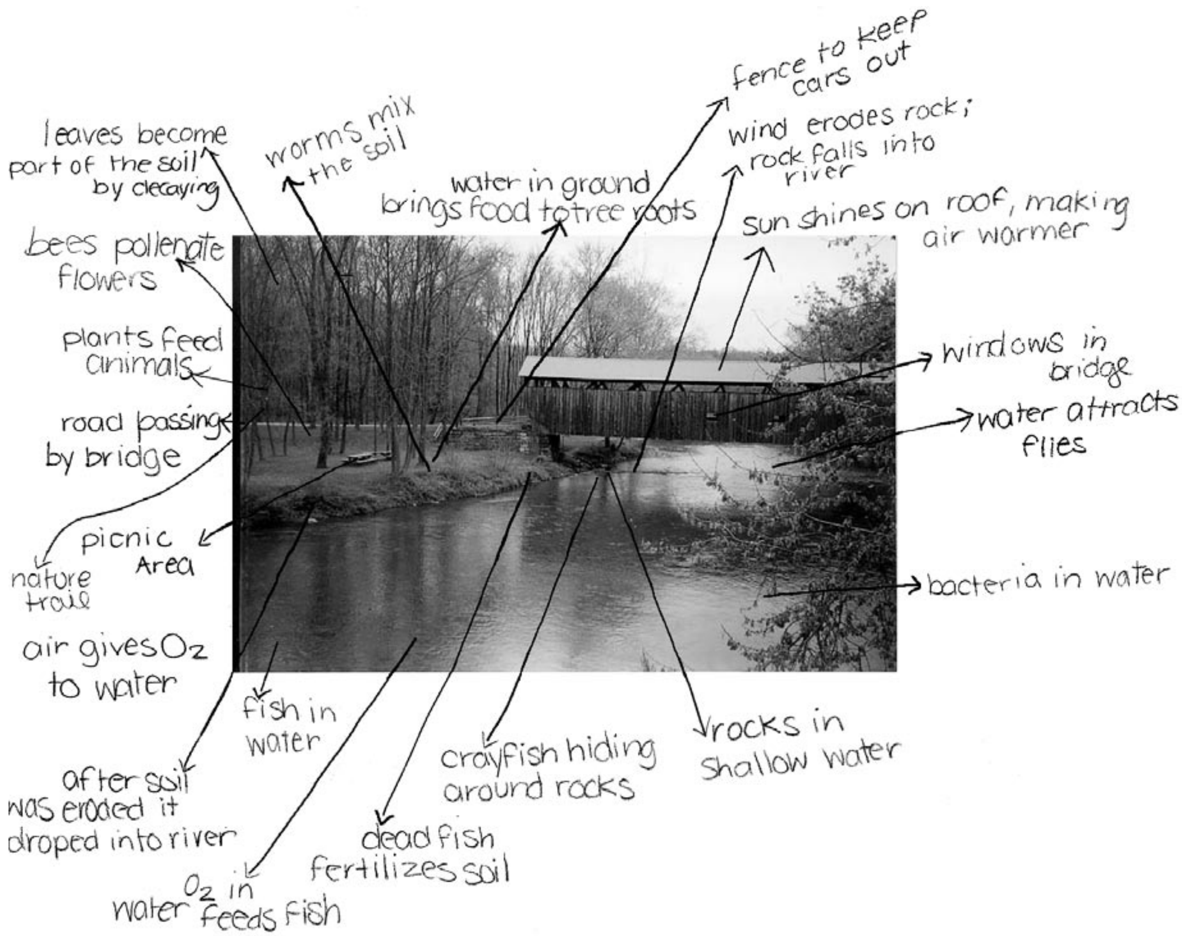


Figure EA-LC2-3: Annotated Literal Diagram of Hydrology Study Site at Reynolds Jr. Sr. High School

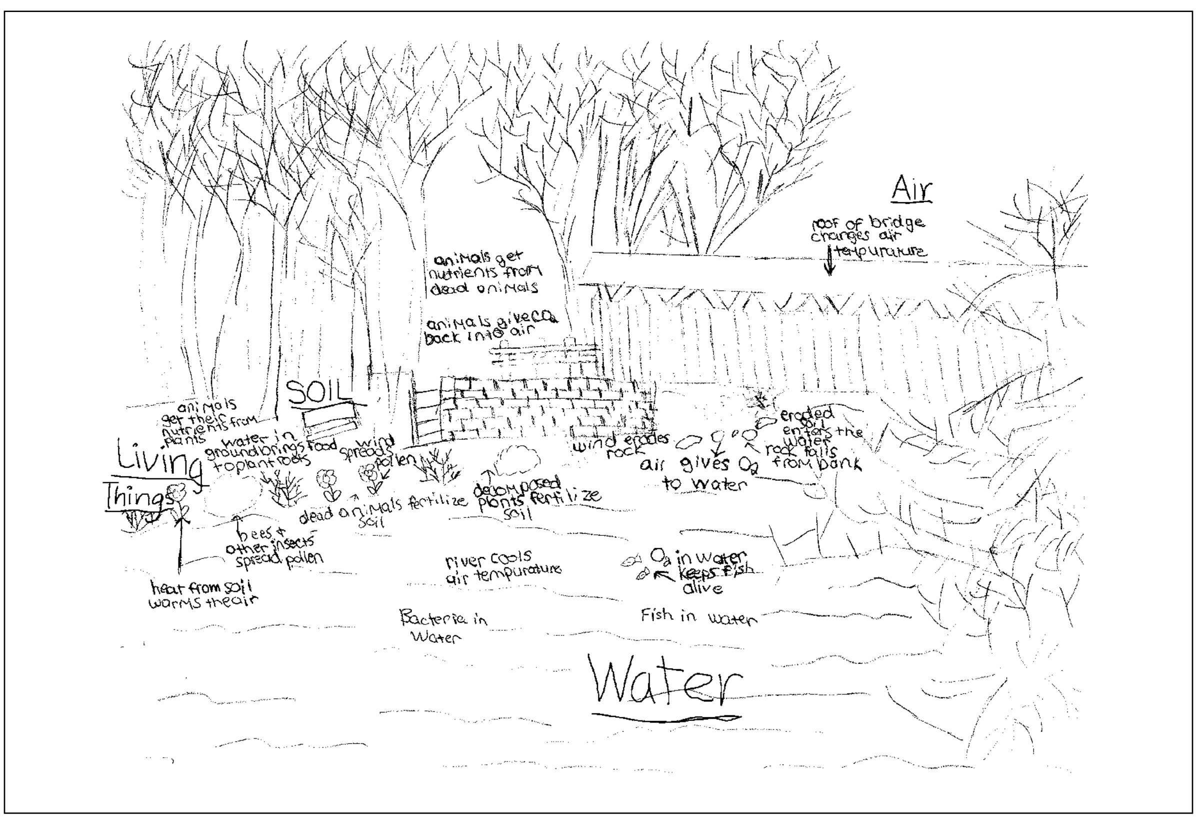
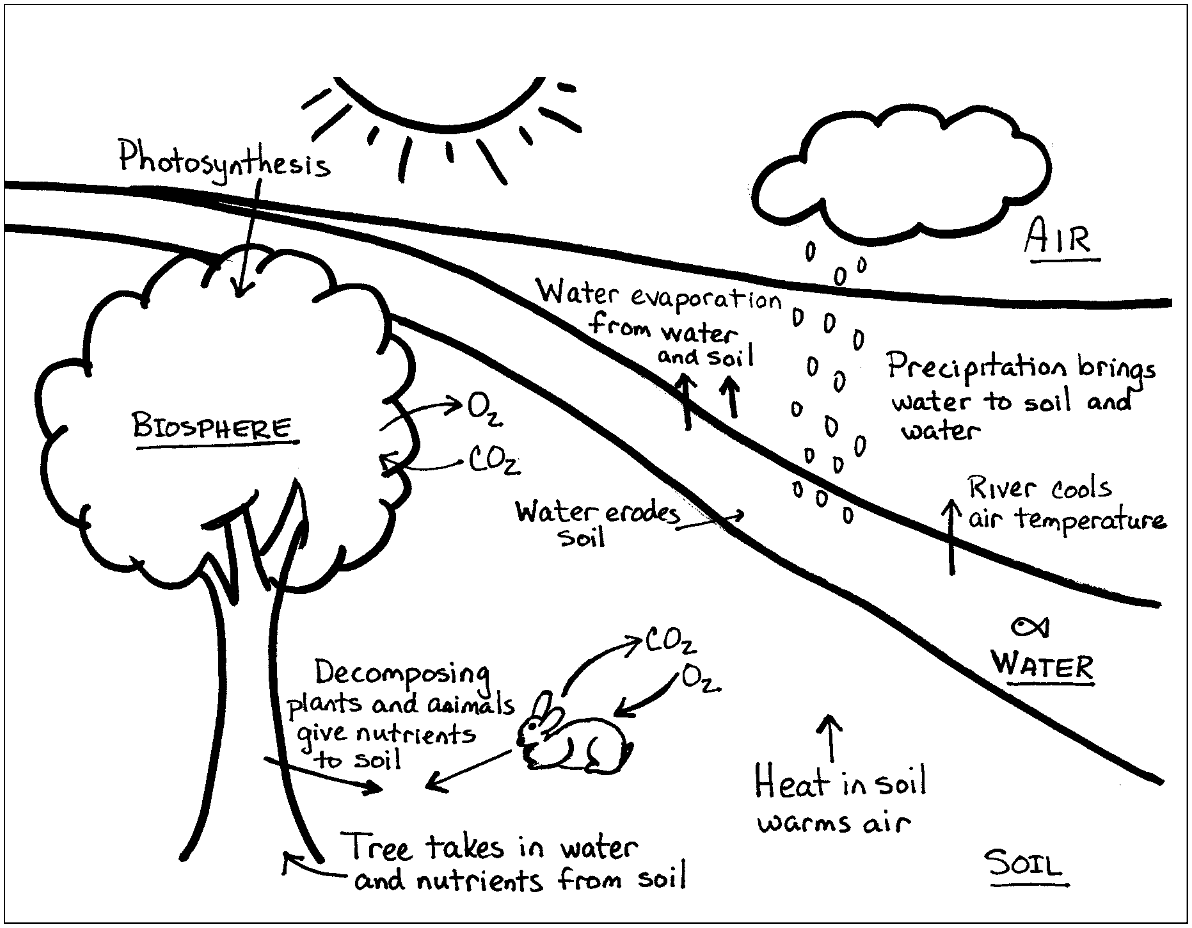


Figure EA-LC2-4: Annotated Simplified Diagram of Hydrology Study Site at Reynolds Jr. Sr. High School



Annotating a Study Site Photograph

Work Sheet-1

Name:_________________________________ Class: _______________________Date:___________

To annotate means to describe with short notes. Annotate your study site photograph (on the sheet to which your photograph is attached) in the following way:

1. Label the four major components of the study site system: atmosphere, hydrosphere, pedosphere (soil), and biosphere.

2. Using the list of interconnections you developed in the previous activity, or the list that GLOBE has provided, write short descriptions of the interconnections among the components of the system, as shown in the photograph.

Follow these guidelines:

1. Use phrases or short sentences with verbs.

2. Make sure you are describing *connections* or *relationships* between components of the system, just as in the list of interconnections.

3. *Write as clearly as possible.* Remember that other students must be able to understand your work.

4. If you run out of space for your annotations, put a number next to the feature in the photograph that you're writing about, draw a small circle around the number so that it will be easy to see, and write the annotation on a separate piece of paper. Attach the piece of paper to your photograph.

5. If your photograph does not show important features that you know about at the study site, you can include them in your annotations in the same way as suggested above.

6. Attach your photograph with annotations to this sheet.

The Study Site as a System

Work Sheet-2: Student Self-reflection Log

Name:________________________________ Class: ______________________Date:___________

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you may need help understanding. *You will not be graded on these responses.*

1. What have you learned about ways that the components of a study site interact as a system, that you feel confident about?

   ____

   ____

   ____

   ____

   ____

2. What are you having trouble understanding about the interactions among components of a study site?

   ____

   ____

   ____

   ____

   ____

3. What would you like to know more about?

   ____

   ____

   ____

   ____

   ____

Diagramming Your Study Site (Literal Diagram)

Work Sheet-3

Name:_________________________________ Class: ________________________Date:____________

Use your annotated photograph to make a literal diagram of your study site. The purpose of this diagram is for you to communicate what you see as the components of the Earth system in your study site and how they interact with each other. If you have trouble drawing, use simple shapes to indicate different things and label them.

Follow these guidelines in creating your literal diagram.

1. In your literal diagram include and label every component of the Earth system that appears in your annotated photograph.

2. Indicate all of the interconnections you identified in your annotated photograph using the phrases or short sentences with verbs to describe them. Be sure to indicate where the interconnection is and between what components it is occurring.

3. In creating your literal diagram are there any other components that you did not notice or label before? If so, add those components to your literal diagram and label them.

4. In creating your literal diagram are there any other interconnections between components that you did not label on your annotated photograph? If so, add those to your literal diagram now. Be sure to indicate where the interconnection is and between what components it is occurring.

Diagramming Your Study Site (Simplified Diagram)

Work Sheet-4

Name:________________________________ Class: ______________________Date:___________

First of all, there is *no one right way* to make a diagram. Your style of diagramming may be very different from someone else's. What matters is that it is *accurate* and *complete,* and that it *clearly communicates your ideas.* Other students must be able to understand your idea just by looking at the diagram.

Second, you may want to revise this diagram more than once. Make it as good as you can, but be aware that you will have opportunities to revise it.

Use your annotated photograph and your literal diagram as the basis for this diagram. Follow these guidelines:

1. Draw and label the four major components of the study site system. (By now you should know what they are!)
2. Use arrows to represent the verbs you used in your annotated photograph and your literal diagram. Draw one-headed arrows to indicate in which direction each interaction is occurring. Show only one direction on each arrow.
3. On the shaft of the arrow, indicate what is moving from one component to the other (such as rain moving from atmosphere to pedosphere).

Be aware that as you simplify your literal diagram into a simplified diagram, you will make decisions about what is most important to keep. This means that you are making decisions about what the essential elements of the Earth system at your study site are.

4. Attach your work to this sheet.

What Have You Learned from Diagramming Your Study Site?

Work Sheet-5: Student Self-reflection Log

Name:________________________ Class: ____________________Date:__________

1. What have you learned about the study site itself?

2. What have you learned about diagramming?

3. What qualities or diagramming techniques did you find valuable in your partner's diagram?,

Assessment Rubric: *LC2: Representing the Study Site in a Diagram*

Annotated Photographs of the Study Site

	4	3	2	1
Study Site Components Included	Includes and correctly identifies all 4 major components	Includes and correctly identifies 3 major components	Includes and correctly identifies 2 major components	Incompletely and/or incorrectly includes and identifies major components
Scientifically Accurate Interconnections	Lists several scientifically accurate interconnections for each component of study site; reflects all of expected science knowledge	Lists 2-3 scientifically accurate interconnections for each component of study site; reflects most of expected science knowledge	Lists 1 or 2 scientifically accurate interconnections for 2 or 3 components of study site; reflects some of expected science knowledge	Lists no scientifically accurate interconnections; reflects little expected science knowledge
Clarity of Descriptions	Writes clearly and succinctly; uses verbs and specific references to indicate all interconnections	Writes clearly; uses verbs and specific references to indicate most interconnections	Needs to improve clarity of writing; uses vague references to indicate most interconnections	Needs to improve clarity of writing significantly

Assessment Rubric: *LC2: Representing the Study Site in a Diagram*

Diagrams of the Study Site

	4	3	2	1
Study Site Components Included	Includes and correctly identifies all 4 major components	Includes and correctly identifies 3 major components	Includes and correctly identifies 2 major components	Incompletely and/or incorrectly includes and identifies major components
Interconnections Represented knowledge	Fully develops interconnections among all components of site, and demonstrates all expected science knowledge	Adequately develops interconnections among all components of site, and demonstrates most expected science knowledge	Partially develops interconnections among components of site, and demonstrates some expected science knowledge	Inadequately develops interconnections among components of site, and demonstrates little expected science
Choices for Simplification in Diagram	Chooses appropriate representations of components and interconnections to depict essence of study site as a system	Chooses mostly appropriate representations of components and interconnections to depict essence of study site as a system	Chooses some appropriate representations of components and interconnections to depict essence of study site as a system	Chooses inappropriate representations of components and interconnections to depict essence of study site as a system
Information Source Designations (D, B, S)	Identifies all information sources accurately and thoughtfully	Identifies most information sources accurately and thoughtfully	Identifies some information sources accurately and thoughtfully	Identifies few or no information sources accurately or thoughtfully
Clarity and Legibility	Writes and draws very legibly and clearly, with no errors	Writes and draws legibly and clearly, with few errors	Writes and draws unclearly, with some errors.	Writes and draws very unclearly, with many errors.

Assessment Rubric: *LC2: Representing the Study Site in a Diagram*

Interpersonal Skills: Receiving and Giving Feedback on Diagrams

	4	3	2	1
Listening Skills	Actively listens, and appears to highly value the constructive ideas of others	Listens, and appears to value the constructive ideas of others	Listens with less than complete attention; appears to somewhat value the constructive ideas of others	Appears to need significant improvement in listening skills, and in valuing the constructive ideas of others
Approach When Giving Feedback	Always uses constructive language; offers encouragement and specific suggestions	Usually uses constructive language; offers general suggestions	Sometimes uses constructive language	Rarely uses constructive language

Assessment Rubric: *LC2: Representing the Study Site in a Diagram*

Designating Information Sources for Interconnections

	4	3	2	1
Information Source Designations (D, B, S)	Identifies all information sources accurately and thoughtfully thoughtfully	Identifies most information sources accurately and thoughtfully	Identifies some information sources accurately and or thoughtfully	Identifies few or no information sources accurately

LC3: Using Graphs to Show Connections

Purpose

To show how graphs of GLOBE data over time show the interconnectedness of Earth's system components at the local level

Overview

The class explores interconnections among Earth system components by creating graphs of GLOBE student data on air and soil or water temperatures. More advanced students can create graphs with other connected variables, such as precipitation and soil moisture. The class analyzes and interprets these graphs, in response to guidance questions. Each student writes a description of the major interconnections and other variables they have detected in the graphs.

If the school has not yet collected 12 months of its own GLOBE data this study, the class works with data from Reynolds Jr. Sr. High School, a GLOBE school in Greenville, Pennsylvania, USA.

Student Outcomes

Students will be able to:

- Analyze and interpret a graph of GLOBE data that shows air and soil or water temperatures over a year;
- Explain how graphs of GLOBE data can show relationships among components of an Earth system.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Making graphs on the Internet

Analyzing and interpreting graphs

Use appropriate tools and techniques.

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Use appropriate mathematics to analyze data.

Communicate results and explanations.

Time

45 minutes

Level

Middle, Secondary

Materials and Tools

GLOBE Graphing Tool on the GLOBE Web site

Printer (to print graphs of GLOBE data)

Graph paper: 1-2 pieces for each student

Preparation

Make graphs in advance.

Make student copies.

Prerequisites

None

What To Do and How To Do It

Step 1. Preparation

Make the Graphs

It is recommended that you make the graphs suggested in this activity before making them with students. It is also recommended that you print and copy the graphs for student use, even if students will be making them on computers themselves. If you need to renew your familiarity with the GLOBE Graphing Tool, see *Using the GLOBE Graphing Tool* in the *Toolkit* section.

Four graphs with GLOBE student data from Reynolds Jr. Sr. High School are provided for you to copy if needed.

Make Student Copies

Analyzing and Interpreting Graphs Work Sheet

Assessment rubric for this activity (You may want to share with students.)

If you have conducted Activity LC2, go to Step 4.

Step 2. *(Begin here if you have not conducted both Activities LC1 and LC2.)* **Introduce the activity with a discussion of dramatic events or changes that have occurred in your local area.** Ask students to suggest events or changes, such as drought, flood, hurricane, fire, or loss of a particular habitat such as a wetland. Have students describe these events. What changed? What do people understand about it? What don't people understand? What do we still need to find out?

Explain that a new discipline of science – Earth system science has emerged, through which people attempt to understand changes like these by learning more about ways that parts of the Earth interact to make the whole. The discipline of Earth system science integrates all sciences that are concerned with the Earth: geology, hydrology, chemistry, botany and zoology, and meteorology.

People who study the Earth as a system are pioneers in this new discipline, and, as experts on their own local areas, GLOBE students can participate. Every area, every site is unique in certain ways. Ask students: How would you apply Earth system science to one of your study sites? How would you communicate the *system* aspect of your study site, its parts and how they interact, to another GLOBE school?

Explain that each one of the activities in the *Local Connections (LC)* series addresses aspects of this question.

Step 3: Introduce this activity.

Your students have explored their GLOBE study sites by making observations, gathering data, and conducting other investigations. For students who will be making graphs of the GLOBE data taken at Reynolds Jr. Sr. High School, photographs taken in the four cardinal directions from the hydrology study site are presented in Figure EA-LC3-1. These photographs will give students fuller knowledge of what that study site looks like. Let the students know that in this activity, they will explore the Earth as a system by graphing GLOBE data, looking for relationships between these components of their locality: air, and soil or water.

What are some relationships between air and soil or water? Conduct a brief discussion. If students do not mention the exchange of heat among those system components (also known as the energy cycle), suggest it to them.

They may have read about this exchange of heat, and of the relationships between air and soil or water, but have they seen supporting data? They can make graphs of GLOBE data and look for evidence of the relationships.

If you have not conducted the previous activity, Activity LC2, skip Step 4 and go directly to Step 5.

Step 4. Refresh your students' memories of the previous activity, in which they found that diagramming is a way to explore and understand a study site as a system.

Remind students that in that activity, they made diagrams to present and illustrate their ideas about interconnections among four major components of the study site: atmosphere, hydrosphere, pedosphere, and biosphere. As a refresher, ask them to briefly describe two or three of those interconnections. Tell them that in this activity, they will explore interconnections in another way: by making graphs of GLOBE student data on the computer.

Step 5. Explain what the graphs are to show.

Distribute the Student *Work Sheet Analyzing and Interpreting Graphs*. Explain that each graph is to show 12 months of data, or one annual cycle. Each data point on the graph will represent an individual measurement. Ask students:

- What would happen if you made graphs that showed the average for each month, rather than for each day that data were collected?

  (The graph would have many fewer data points and that you would not be able to see the day-to-day variations.)
- What would you be able to learn from a graph of monthly averages?

  (You would be able to learn general trends in temperatures throughout the year.)
- What would you *not* be able to learn?
  (You would not be able to learn about the effects of short-term events, such as storms, on temperatures, nor about the finer details of possible relationships among air and soil or water temperatures.)

It is recommended that students graph data from their own school. If the school has not collected a full year of GLOBE data on air and soil or water temperatures, students can graph data from Reynolds Jr. Sr. High School, a GLOBE school in Greenville, Pennsylvania, USA. See Figures EA-LC3-2 through EA-LC3-5.

Advanced students will be able to make more complex graphs, including different types of data such as in Figure EA-LC3-5, than middle students will, and they will be able to explore graphing GLOBE data in more sophisticated ways.

Step 6: Have the class use the GLOBE Visualization tool to make the first graph, Maximum Air Temperature Over a Year. Ask them questions to help them with analysis and interpretation of the graph. Note for teacher: The explanations given for why the system responds the way that it does at Reynolds Jr. Sr. High School in this and the following steps may not apply to your local study site. If your data show different relationships than those for Reynolds, have your students describe the differences and speculate why they might be different.

If computers are not available, use copies of printed versions of the graphs for students to study and interpret. See Figures EA-LC3-2 through EA-LC3-5.

Have students open the GLOBE Visualizations software on the GLOBE Web site, and go to GLOBE Graphs - Time Plots of Student Data. Have them make a graph of maximum air temperature over a year from their own school or from Reynolds Jr. Sr. High School's Atmosphere Study Site (also known as "ATM-02 Weather Station"). (Reynolds Jr. Sr. High School data for 1998 are shown in Figure EA-LC3-2.) Ask students to respond to the questions below about the graph, using their *Work Sheets*. Give students 5 minutes to write their responses, then discuss the questions as a class. At the end of the activity, there is an opportunity for students to revise their responses before you collect the *Work Sheets*.

Desired student responses appear in parentheses.

- What month has the highest maximum air temperatures? Why?

  (In the graph of Reynolds Jr. Sr. High School data, July and August have equally high surface air temperatures. While the summer solstice is in June, the Earth system takes some time to fully respond. As a result, maximum temperatures occur in July and August at Reynolds. In many places in the Northern Hemisphere , the maximum temperatures are in August. Warm air temperatures continue into some days of September and early October, but there are some days in those months with lower temperatures than any in July and August.)

- What month has the lowest maximum air temperatures? Why?

  (In the graph of Reynolds Jr. Sr. High School data, December has the lowest air temperature. There must have been an especially cold air mass that came through, because normally, the lowest temperatures are later in the winter, when the ground has become consistently cold.)

- What is the range of maximum air temperatures throughout the year (the difference between highest and lowest temperatures)?

  (In the graph of Reynolds Jr. Sr. High School data, the range is +32 C to –12 C, for a range of 44° C.)

Step 7. Have the class make a second graph of soil or water temperature over a year and discuss what it means.

Ask students to respond to the questions below about the graph (the surface water temperature over the year 1998 for Reynolds Jr. Sr. High School is shown in Figure EA-LC3-3), using their *Work Sheets.* Give students 10 minutes (adjust for class needs) to write their responses, then discuss the questions as a class.

- What month has the highest soil (or water) temperature? Why?

  (In the graph of Reynolds Jr. Sr. High School data, the highest water temperature of 24 degrees C is reached in August, with July a *very* close second. The surface air temperature takes some time to fully respond to the highest amount of solar radiation that occurs in June. As a result, the highest water temperatures at Reynolds Jr. Sr. High School occur in August).

- What month has the lowest soil (or water) temperature? Why?

  (In the graph of Reynolds Jr. Sr. High School data, the lowest water temperature is in March, but there are more days of low water temperatures in January and very early February, when the air is coldest. In considering why this happens, remember that the maximum air temperatures are taken every day, and the surface water temperatures are taken once a week. Then look back at the graph of maximum air temperatures at Reynolds Jr. Sr. High School, Figure EA-LC3-2. There are a number of days in March when there are very low maximum air temperature measurements. Since this cold period lasted more than a day, it seems to have affected the surface water temperatures, making one measurement very low also.)

- What is the range of soil (or water) temperatures throughout the year?

(In the graph of Reynolds Jr. Sr. High School data, the range of water temperatures is from 24 degrees Celsius to 1 degree Celsius, or 23 degrees Celsius.)

Step 8. Have the class make a third graph, of surface air temperature and soil or water temperature together, and discuss what it means.

Ask the class what this graph shows about the interconnection between air temperature and soil (or water) temperature , using the questions below. The graph of maximum air, surface water, and soil temperatures over the year 1998 for Reynolds Jr. Sr. High School is shown in Figure EA-LC3-4. Again, give students 5 minutes to write their responses on their *Work Sheets*, then discuss the questions and their responses as a class.

- Do air and soil (or water) temperatures reach their highest values during the same months? Why or why not?

  (Air, water, and soil reach their highest temperature values at different times, because they have different heat capacities. Air and soil absorb and release heat faster than water does. So air and soil will reach their highest temperature value earlier in the year than water will. In the graph of Reynolds Jr. Sr. High School maximum air and surface water temperature for 1998, the air approaches its maximum temperature through the spring faster than the surface water and attains high values a month before the water does. The times of consistently high temperatures for air occur in July and August and for surface water occur in mid July and August)
- Why are the peak values for air and soil (or water) temperatures different? What does this show about the differing characteristics of these two Earth system components?

  (The maximum (minimum) values of maximum air temperature are always greater (less) than the maximum (minimum) values of the surface water temperature. This is because the specific heat of air (the amount of energy needed to increase the temperature of air 1C) is less than the specific heat of water. Therefore, with the same amount of energy input (output) the temperature of the air increases (decreases) more than the temperature of water.)
- What does this graph show about the interconnection between air and soil (or water) temperatures?

  What patterns do you see, if any?

  (Air, water, and soil temperatures follow the same trends during the annual cycle, with water temperatures generally higher in the winter and lower in the summer, and soil temperatures generally lower in the winter and higher in the summer than air temperatures. This is a general pattern; it may vary from region to region.)

If you conducted Activity LC2, go to Step 9.

If you did not conduct Activity LC2, go directly to Step 10.

Step 9. If you conducted *Activity LC2,* **ask the class how the information on this graph is related to their diagrams.**

Did any students include the transfer of heat energy in their diagram of the study site during the previous activity? Explain that heat does move from air to soil, soil to air, air to water, and water to air. The direction of the transfer of heat depends on which is warmer. If the air is warmer, the heat transfer is from the air to the soil or water, and if the soil or water is warmer, the heat transfer is from the soil or water to the air .

Step 10. Give students a few minutes to complete their written responses to the questions on their *Work Sheets,* **including the** *Self-Reflection Log* **questions, then collect the** *Work Sheets.*

If there is not enough class time for this step, students can complete their *Work Sheets* as homework.

If you can review the *Work Sheets* before conducting the next activity, you will have an opportunity to shape your teaching of that activity in light of student responses to the self-reflection log questions.

Step 11. If you plan to conduct *Activity LC 4,* **prepare students for it.**

Let students know that in the next activity, they will develop a class diagram and description of their study site, to share with other GLOBE schools.

Student Assessment

The *Analyzing and Interpreting Graphs Work Sheet,* can be used for assessment. An assessment rubric is provided.

The last section of the *Work Sheet* is for student self-reflection, and student responses to those questions are not quantifiable.

If time permits, as an assessment task, you can ask students to make the same graphs as were required in this activity, using data from other GLOBE schools. The same rubrics on analysis and interpretation of graphs can be used for assessing this student work.

Further Investigations

Graphing More GLOBE Data

As an extension of step 8, have students speculate about other interconnections between Earth system components that one might explore by making graphs.

Have students retrieve their diagrams from *Activity LC2,* or use the sample diagram provided for that activity, and have them use the diagrams to help them generate ideas. Conduct a short class discussion about other interconnections they might explore in graphs.

For more advanced students, the teacher can suggest further investigations with GLOBE school data.

Some ideas for interconnections students may explore by graphing and analyzing the data:

Air temperature, precipitation, and soil moisture (Figure EA-LC3-5)

Air temperature and soil temperatures at 5 cm and 10 cm

Air temperatures and soil moisture at various depths

Precipitation pH, water pH, and soil pH

Air temperature, rainfall and snowfall

Have the students examine the graphs they create to see where variables change with some consistent relationship to each other. For example, look at Figure EA-LL-56. This figure shows the monthly average maximum air temperature, precipitation, soil moisture at 10 cm, and soil moisture at 90 cm at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA from April 1, 1998 through October 1, 1998. You can see that as the temperature rises from the spring to the summer the soil moisture decreases, with the soil moisture decreasing earlier and to a greater degree at 10 cm compared to at 90 cm. This occurs because as the temperature rises, evaporation increases, drying out the soil. The soil nearer the surface dries out sooner and more fully because it is closer to the warm atmosphere. This pattern can be seen as a consistent one if you look at how these variables vary over many years. In addition, you can see that after each precipitation event the soil moisture near the surface increases for a short time, then returns to its steady decrease from spring to summer as the temperatures rises. This is a consistent pattern over the period shown in the graph. Thus this graph shows interconnections between the atmosphere (temperature and precipitation) and soil (soil moisture).

As a follow-up to this activity, have your students graph data from other GLOBE schools to explore interconnections among components of the Earth system at those study sites.

Let your students know that ecological and physical characteristics of study sites at GLOBE schools around the Earth differ, and therefore, interactions among study site components can differ from site to site as well. The specific relationships for which your students find evidence at their site may not appear in data from another school. This does not mean your students should discount what they find in their graphs of other schools' data; rather, it should reflect to them the diversity and complexity of the Earth system in which we live.

Figure EA-LC3-1: Photographs of Reynolds study site in four cardinal directions from the Hydrology study site a) North, b) East, c) South, d) West. The photograph of the Reynolds Jr. Sr. High School study site appears in Figure EA-LC2-1.

a. North

b. East

c. South

d. West

Figure EA-LC3-2: Maximum Air Temperature at Reynolds Jr. Sr. High School 1/1/98-12/31/98

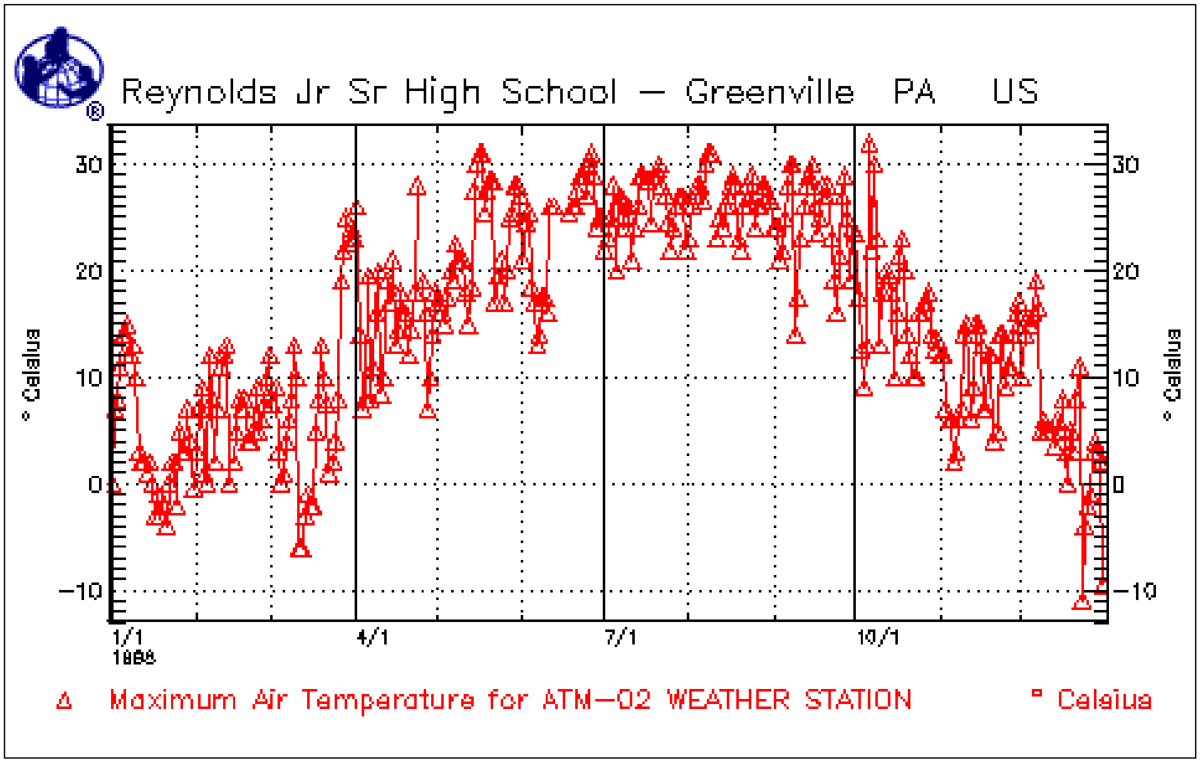


Figure EA-LC3-3: Surface Water Temperature at Reynolds Jr. Sr. High School 1/1/98-12/31/98

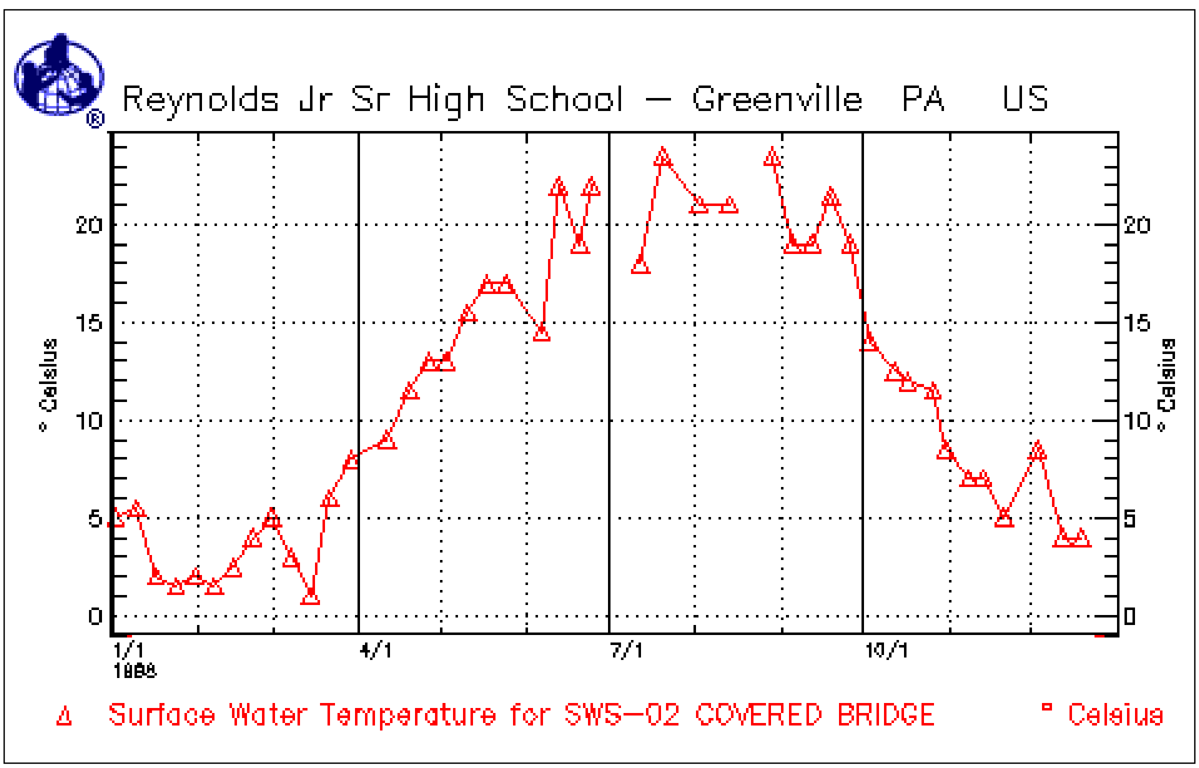


Figure EA-LC3-4: Surface Water, Maximum Air, and Soil Temperature at Reynolds Jr. Sr. High School 1/1/98-12/31/98

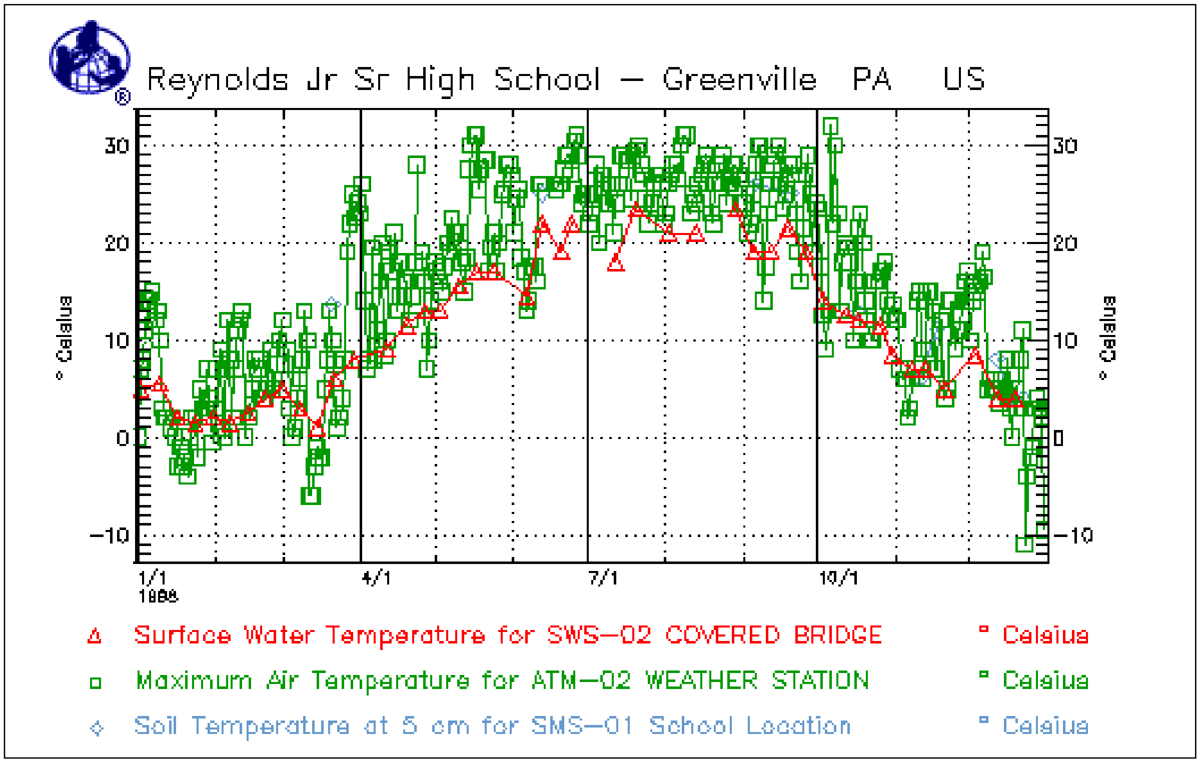
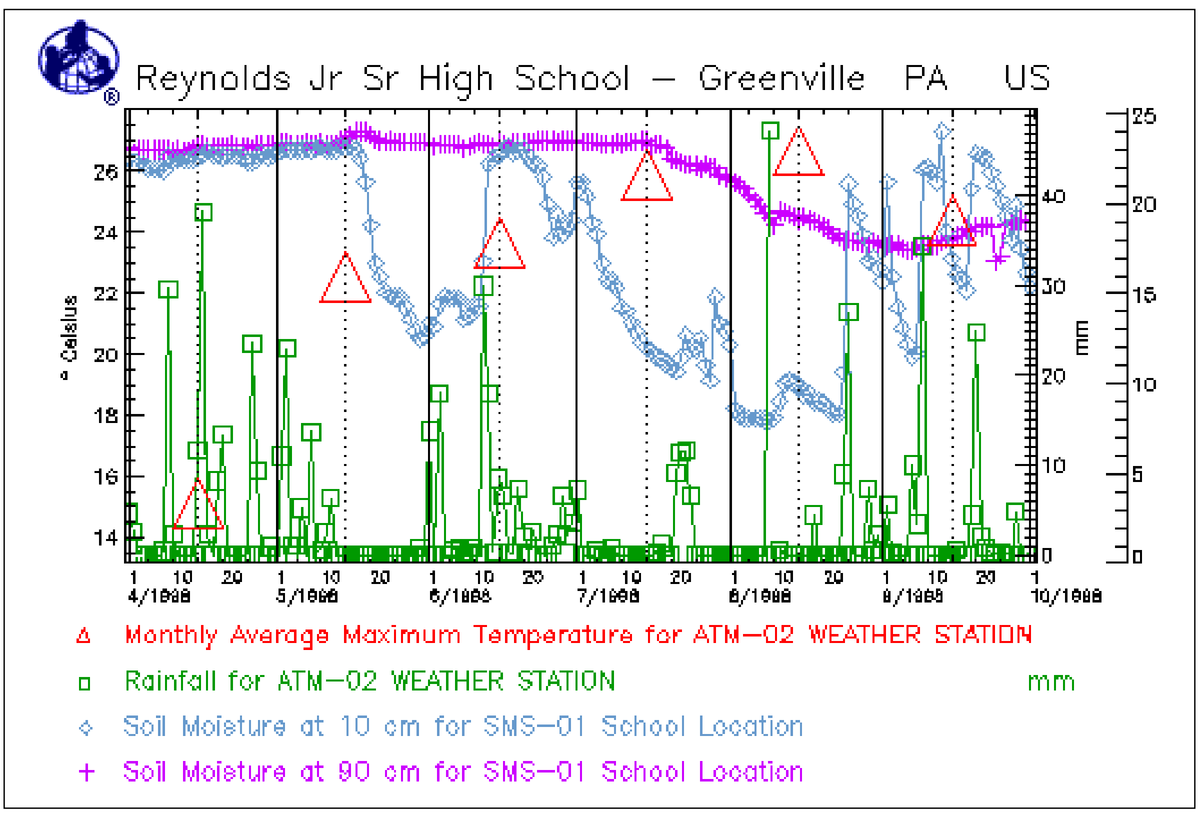


Figure EA-LC3-5: Monthly Average Maximum Temperature, Precipitation, Soil Moisture at 10 cm and Soil Moisture at 90 cm at Reynolds Jr. Sr. High School 1/1/98-12/31/98



Analyzing and Interpreting Graphs

Work Sheet

Name:__________________________ Class: ____________________Date:__________

1. First Graph: Maximum Air Temperature Over a Year

a. What month has the highest maximum air temperatures? Why?

____

____

____

b. What month has the lowest maximum air temperatures? Why?

____

____

____

c. What is the range of maximum air temperatures throughout the year (the difference between highest and lowest temperatures)?

____

____

____

2. Second Graph: Soil or Water Temperature Over a Year

a. What month has the highest soil (or water) temperature? Why?

____

____

____

b. What month has the lowest soil (or water) temperature? Why?

____

____

____

c. What is the range of soil (or water) temperatures throughout the year?

____

____

____

3. Third Graph: Maximum Air Temperature and Water or Soil Temperature

a. Do air and soil (or water) temperatures reach their highest values during the same months? Why or why not?

b. Why are the peak values for air and soil (water) temperatures different? What does this show about the differing characteristics of these two Earth system components?

c. What does this graph show about the interconnection between air temperature and soil (or water) temperatures? What patterns do you see, if any?

4. Other Earth System Relationships

What other relationships among study site system components do you think might be worth investigating, and what data would you need? Suggest only relationships that you think data could be obtained for. Think about all the interrelationships that you and other students may have listed and diagrammed.

(Did you list both the relationships to investigate *and* the data you would need?)

5. Self-reflection

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you need help understanding. You will not be graded on these responses.

a. What have you learned in this activity that you feel confident about?

____

____

____

____

____

b. Which of the following areas, if any, are you having trouble understanding? Please check those

that apply, and describe what is giving you difficulty.

___ Making graphs from GLOBE Data Archive

___ Reading and interpreting graphs

___ Interpreting relationships among different components (air, soil, water)

___ Understanding the relationship of the graph to your own study site

____

____

____

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c. What would you like to know more about?

____

____

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____

Assessment Rubric: *LC3: Using Graphs to Show Connections*

Analyzing and Interpreting Graphs of GLOBE Data on Surface Air Temperatures and Soil or Water Temperatures

	4	3	2	1
Analysis of Graphs	Identifies highest and lowest values and ranges with no errors	Identifies highest and lowest values and ranges with few errors	Identifies highest and lowest values and ranges with some errors	Inaccurately identifies highest and lowest values
Interpretation of Graphs	Accurately and precisely identifies seasonal change patterns in data, and fully explains relationships among components	Accurately and generally identifies seasonal change patterns in data, and indicates relationships among components	Partially identifies seasonal change patterns in data and vaguely indicates relationships among components	Inaccurately identifies change patterns in data and neglects to explain relationships among components
Suggestions of Other Relationships	Suggests 3 or more other scientifically appropriate relationships to investigate; lists data needed	Suggests 2 other scientifically appropriate relationships to investigate; lists some data needed	Suggests 1 or 2 other scientifically appropriate relationships to investigate; lists little of the data needed	Suggests no other scientifically appropriate relationships to investigate

LC4: Diagramming the Study Site for Others

Purpose

To develop the best possible representation of the study site as a system

Overview

Working in small groups, students compare and contrast individual diagrams, in terms of the lucidity of their expression of the key components and interconnections in their study sites. Selecting the best of their components and interconnections, the class combines them to produce a summary diagram of their study site.

Student Outcomes

Students will be able to:

- Interpret and evaluate diagrams of their local study site in terms of their key components and interconnections;
- Describe and justify their views on what makes an effective diagram of an Earth system.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Collaborating to develop a class product

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

Two 45-minute class periods

Level

Middle, Secondary

Materials and Tools

Student study site diagrams or sample set from Reynolds Jr. Sr. HS study site

Preparation

None

Crosswalk to Another GLOBE Learning Activity

Earth as a System Investigation-Seasons and Phenology: What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?

Teachers and students share seasonal marker observations, which are the various changes that mark transition points in the annual cycles of seasons. (Examples are the first snowfall, the beginning of monsoon rains, and the summer solstice.) Students compare GLOBE data with the observations they take at their study site. The activity promotes collaborations among GLOBE classes, and helps teachers and students learn how to work with the GLOBE data system and GLOBEMail email.

What To Do and How To Do It

Step 1. Make Student Copies

If you did not conduct *Activity LC2*, and your students have not created diagrams of their own study site from which to develop a class diagram, make student copies of Figure EA-LC2-1 (in *Activity LC2*), and Figure EA-LC3-1 and EA-LC4-1 (in *Activity LC3*)

Also, copy the two *Work Sheets* (*Characteristics of an Effective Diagram* and *Questions to Describe the Study Site*), and the *Study Site Description Form*. You may also want to copy the *Assessment Rubrics* to share with students.

Step 2. Revisit or discuss the dramatic events or charges that have occurred in your local area.

Ask students to suggest events or changes, such as drought, flood, hurricane, fire, or loss of a particular habitat such as a wetland. Have students describe these events. What changed? What do people understand about it? What don't people understand? What do we still need to find out?

Explain that a new discipline of science has emerged with which people attempt to understand changes like these by learning more about ways that parts of the Earth interact to make the whole. The discipline of Earth system science integrates all sciences that are concerned with the Earth: geology, hydrology, chemistry, botany and zoology, and meteorology.

People who study the Earth as a system are pioneers in this new discipline, and, as experts on their own local areas, GLOBE students can participate. Every area, every site is unique in certain ways. Ask students: How would you apply Earth system science to one of your study sites? How would you communicate the *system* aspect of your study site to others?

Explain that each one of the activities in the *Local Connections (LC)* series addresses aspects of this question.

Step 3. Organize students into small groups of 3-6 students each, and introduce the activity.

Distribute the simplified diagrams created by your students if you conducted *Activity LC2,* or if you did not conduct *LC2* distribute copies of the five photographs (Figures EA-L-48 and EA-L-52) and the four simplified diagrams provided for this activity (Figure EA-L-57). Also, distribute the *Characteristics of an Effective Diagram Work Sheet*.

Explain to students that in the course of this activity, they will develop a class diagram of their Earth system study site as a system (showing its four major components, and the interconnections among them), and a short description of the study site. (If your students did not conduct *Activity LC2* you will create a class diagram for Reynolds Jr. Sr. High School from photographs and diagrams provided by GLOBE). Tell them that a significant skill involved here is collaboration.

Step 4. If you conducted *Activity LC2,* **give students a few minutes to revise their own diagrams if they wish.**

Students who are working with their own diagrams may have additions or changes to make to them. Students who are working with the diagrams provided by GLOBE can make additions to them that reflect either their existing knowledge of their own study sites or information that they can gather by using the photographs of the hydrology study site and in the four cardinal directions around that site at the Reynolds Jr. Sr. High School study site.

Step 5. Instruct students to discuss and compare the best features of their diagrams.

Distribute the *Characteristics of an Effective Diagram Work Sheet*. Tell students that a spokesperson designated by each group will present and describe the best features of that group's diagrams for the whole class. Spokespersons must justify their groups' opinions about these best features on the grounds of either scientific accuracy or the need for clear communication by the diagram. Explain that each spokesperson's presentation will reflect the work of each student in the group.

Remind students that their ability to work together as a group is an important part of the experience. They must listen to each other with complete attention, comment on each others' work and ideas constructively, and reach consensus out of full participation by all members of the group. Encourage students to evaluate their teammates' diagrams carefully, to ask questions about aspects that are unclear, and to offer constructive criticism. Help them to be aware that although they may reach consensus about the appearance and characteristics of a good diagram, the styles and approaches of different students will vary. This in itself is a valuable lesson for students. The same phenomena can be represented in ways that are different, yet equally valid if they are based on accurate information.

Instruct students that in the course of the group's work, each student should make notes on what she or he considers to be the characteristics of an effective diagram.

Step 6. Have each group's spokesperson present and describe the best features of that group's diagrams to the whole class.

Diagrams being discussed can be passed around, or redrawn on the blackboard.

Let students know that during this time, they can modify their individual lists of the characteristics of an effective diagram, as they review the diagrams of others and participate in the class critiques.

Have one or two students keep track of the best diagram features that are identified by the class, making notes and sketching on the blackboard, as the presentations and discussions proceed.

Step 7. Help the class to reach consensus on what should be in the class diagram and how it should look.

The class must reach consensus on the best diagram to represent their ideas about interconnections at their study site. As features of the class diagram take shape, a student (or students) designated by the teacher can sketch the diagram on the blackboard.

Step 8: Distribute the *Questions to Describe the Study Site Work Sheet*. **Have students develop a list of the questions, the answers to which they think will describe their study site.**

Explain to students that in addition to the class diagram of the study site, they will create a description of it.

A *Study Site Description Form* is provided, but before introducing it to students, have them suggest what information should be included in such a form. What would you want to tell other students about your study site, so that they would understand it as a system as fully as possible?

Reinforce the students' awareness that this is important work, because they are the experts on their study site. Nobody knows it as well as they do.

Illustrative student responses:

- Is the area in a temperate, tropical, or polar climate?
- What is the range of temperatures throughout the year?
- What are the seasons, and when do they occur?
- How much rain and snow does the site get, and when does it fall?
- How often are there storms?
- How cloudy is it throughout the year?
- What species of plants, animals, and other organisms live here?
- How does the vegetation change over the year?
- How do animal populations change over the year? Do some animals migrate from or into the area during different seasons?
- Is the soil sandy, sticky, or hard? Is it wet or dry?
- Is the site in an urban, suburban, or rural area?
- How far is the site from an ocean or other large body of water? Does this body of water lie to the north, south, east, or west of the site? What is unique or special about this site?

Step 9. Designate one of the students to draw the final version of the class diagram on a piece of paper.

Using either the Reynolds diagrams or their own, produce a class compilation of the best features of the individual diagrams.

Sample class diagrams from different climatic regions (one of which is the Reynolds Jr. Sr. High School site) appear in Figure EA-LC5-1 in *LC5: Comparing the Study Site to One in Another Learning Activity.*

Step 10. Distribute copies of the *Study Site Description Form,* **and have students discuss and evaluate the questions on it.**

Ask students to compare the questions on the form with the questions they suggested. Why are these particular questions on the form? Select a few and ask the students, Why might this information be helpful for understanding another school's study site as an Earth system?

It is perfectly acceptable to add questions to the *Study Site Description Form,* if students can explain how those additions will help others to understand their study site as a unique place and as a system.

Allow students to revise their own lists of questions if they wish. Explain that you will be collecting their lists at the end of the activity.

Step 11. Guide students in completing the *Study Site Description Form*, **with descriptions of unique or special features of the study site.**

Students should complete this form as a class, using their own lists of questions to help point out any special aspects or features of their study site that distinguish it from other sites.

Step 12: If you plan to conduct the next activity, *Activity LC 5,* **prepare students for it.**

Explain that in the next activity, students will compare a diagram and description of an Earth system study site from another study site with their own in terms of both science content and style.

Step 13. Have students complete the *Diagramming and Describing the Study Site for Others: Student Reflection Log Work Sheet.*

Student Assessment

Three *Work Sheets* can be used for assessment of student learning:

Characteristics of an Effective Diagram;
Questions to Describe the Study Site;
Student Self-reflection Log: Diagramming the Study Site for Others

Students' collaboration skills can also be assessed.

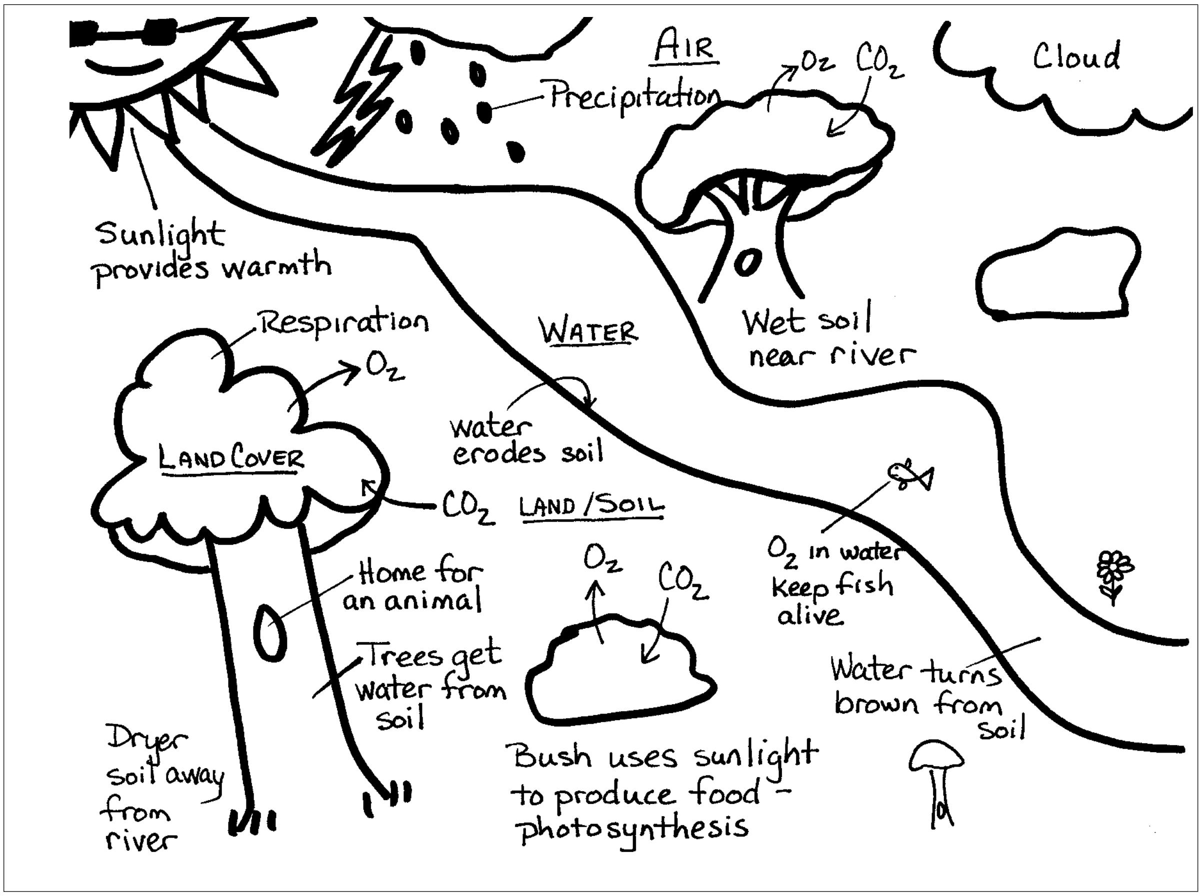
Assessment rubrics for the first two *Work Sheets* and for the collaboration skills are provided.

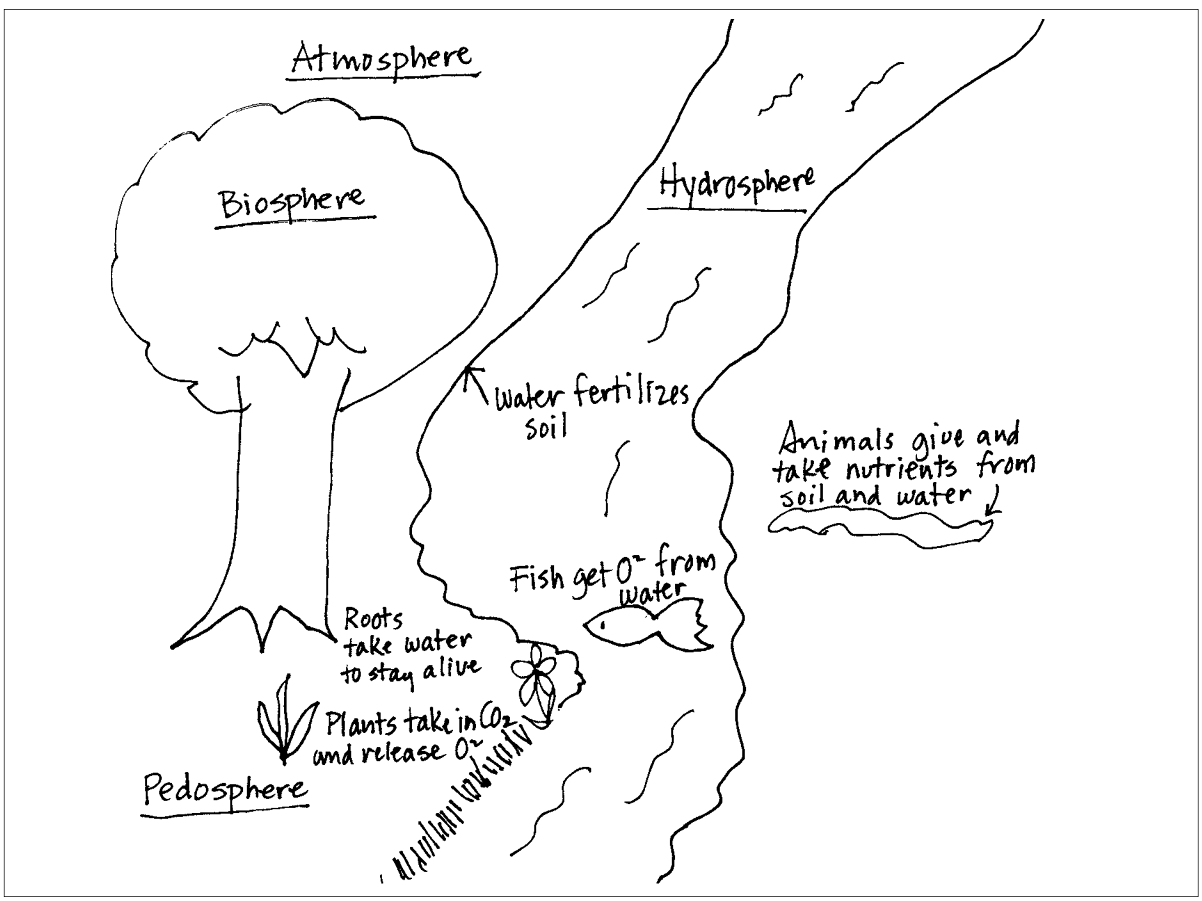
Further Investigations

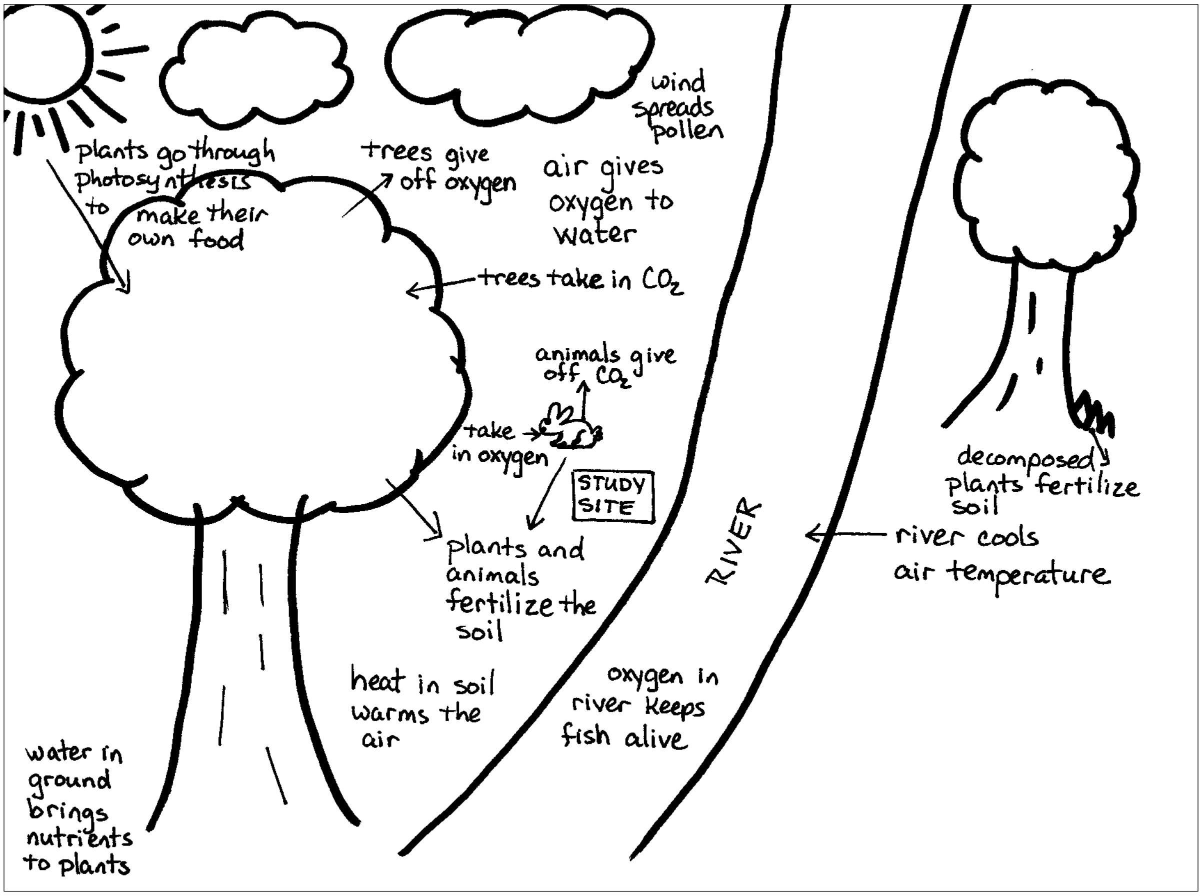
Systems through the Seasons

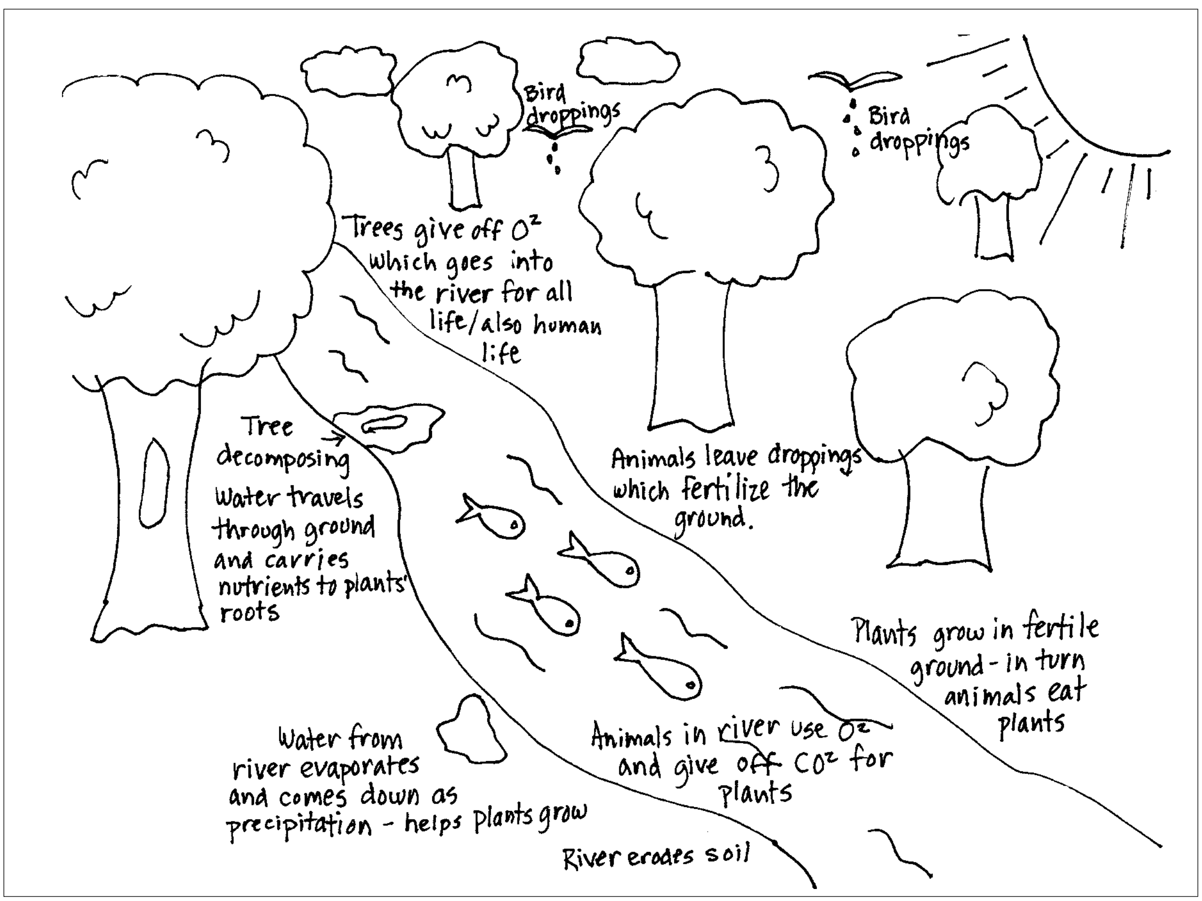
Using photographs of the site (or sites like it) taken in other seasons, ask students to describe how interconnections among Earth system components might be different at those times. How will temperature changes affect interconnections?

Figure EA-LC4-1: Four Sample Simplified Diagrams of the Reynolds Jr. Sr. High School Hydrology Study Site






wind spreads pollen
plants go through photosynthesis to make their own food
trees give off oxygen
air gives oxygen to water
trees take in CO_2
animals give off CO_2
take in oxygen
STUDY SITE
plants and animals fertilize the soil
decomposed plants fertilize soil
RIVER
river cools air temperature
heat in soil warms the air
oxygen in river keeps fish alive
water in ground brings nutrients to plants


Bird droppings
Bird droppings
Trees give off O^2 which goes into the river for all life/also human life
Tree decomposing
Water travels through ground and carries nutrients to plants' roots
Animals leave droppings which fertilize the ground.
Plants grow in fertile ground - in turn animals eat plants
Animals in river use O^2 and give off CO^2 for plants
Water from river evaporates and comes down as precipitation - helps plants grow
River erodes soil

Characteristics of an Effective Diagram

Work Sheet–1

Name:________________________________ Class: ______________________Date:___________

Respond to Questions 1 and 2 below *before* you work to determine best features of your diagrams in small groups.

1. What do you like about the diagrams made by the other students in your group, or, if you used diagrams provided by GLOBE, what do you like about those diagrams? Why?

____

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2. What do you consider to be the characteristics of an effective diagram?
   Think about the diagram as a way of communicating concepts about the study site as a system, in other words, as a set of components that interconnect.

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Tips for Choosing the Best Features of Several Diagrams

Your task is to decide as a group which diagram features and characteristics to recommend to your class, so that the class can make the best possible single diagram to represent your study site as a system, to other GLOBE schools.

Your teacher has given you some diagrams — either diagrams made by students in your class, or diagrams drawn by other students for the GLOBE teacher's guide), as examples to help you. Here are some tips on how to accomplish your task.

For students who did not make their own diagrams in Activity LC2 and are using the sample student diagrams provided by GLOBE: Take heed. These 4 sample diagrams are based on student work, and they are not perfect! They can be improved upon. They will probably not represent your own study site as completely and accurately as you want. The major components may not be labeled, which is a requirement for the class diagram. They may not include all of the interconnections you might think should be on the class diagram, so you may want to add some.

- Make notes on what you like about these diagrams. You can record your ideas in different ways:
  You can make a list of the features and characteristics you want to recommend to the class;
  You can have one of the group sketch a new diagram; or,
  If these diagrams are copies and not original work by classmates, you can highlight or circle what you like directly on them.

- Decide how you want to recommend that your class represent the 4 components of the system on the diagram.
  How do you want to represent the biosphere? Do you want to use a tree, or a bird, or both?
  How do you want to represent the atmosphere? Do you want a cloud?
  How do you want to represent the hydrosphere? A stream, or a lake, or a canal?
  How do you want to represent the pedosphere?

- Decide which interconnections among components you want to recommend for the class diagram. Which are the most important?

- Decide about the style of the diagram. Do you prefer simple, or complex? Are there particular kinds of arrows that you want?

Respond to Questions 3 and 4 below *after* you work to develop a diagram as a whole class.

3. For students who developed their own diagrams of the study site in *Activity LC2:* If you were drawing your own individual diagram of the study site as a system all over again, what (if anything) would you change? Why?

4. What (if anything) would you now add to or delete from your list of the characteristics of an effective diagram, in Question No. 2, above?

Questions to Describe the Study Site

Work Sheet-2

Name:______________________________ Class: ______________________Date:__________

Part 1

Do this part before completing the Earth System Science Investigation *Study Site Description Form* with your class.

Make a list of the questions that you think should be answered to describe your study site to others.
Remember to include questions about climate, elevation, land cover, water, soil, and living things.

Part 2

Do this part after completing the Earth System Science Investigation *Study Site Description Form* with your class.

In this activity, you wrote your own questions to describe your study site for others, and then you discussed and compared those questions with the questions on the GLOBE form. From doing that, what did you learn about describing a study site?

Study Site Description Form

Today's Date: ________________ Season Depicted in Class Diagram: ______________________

1. School Identification

1. School Name: ____

2. School Address:____

____

3. Teacher Name: ____

4. Class Identification: ______________________________________

(**Note:** Since a school may do this activity over a number of years with multiple classes, it is possible that there will be multiple diagrams for the same study site on the GLOBE web site. Therefore, please include here the name of the teacher who guided the development of the class diagram, and any other distinguishing notes about the class):

2. Study Site Location

5. Latitude: ____________________________

6. Longitude: __________________________

7. Elevation (in meters): ________________

8. Is your study site in the interior of a continent (more than 200 km from the coast)? __ Yes __ No

9. Would you describe your site as urban, suburban, or rural? Please check one:

__ Urban (city environment, much of the land surface covered with concrete or other man-made material)

__ Suburban (many man-made structures separated by areas of open land, i.e. land not covered with man-made materials)

__ Rural (farmland, mainly open land with few man-made structures)

3. Climate

10. Please check one:

__ Polar and subpolar (located between 60˚ latitude and the pole)

__ Mid-latitude (located between 30˚ and 60˚ latitude)

__ Tropical and subtropical (located between 30˚ latitude and the equator)

11. What is the average precipitation your area gets in a year? Please give your response in cm. (You can get this information from an atlas, your local library, local civil engineer, or local government) _____________cm

12. Are there months of the year when your area usually gets more precipitation than during other months? ____Yes ____No

If yes, during what months does your area usually get more precipitation?

____

4. Weather

13. Does your weather usually come from one particular compass direction during the season represented in your diagram of the study site as an Earth system? ____Yes ____No

If yes, what *general* direction (N, E, S, or W)? __________________

5. Water

14. Does your study site include part of a body of water, or is it within 100 m of one? ____Yes ____No

If yes, please indicate what type of water body it is by checking one below

If no, please go to Question 18.

__ Stream
__ Canal
__ River
__ Pond
__ Lake
__ Bay
__ Ocean
__ Reservoir
__ Irrigation ditch
__ None

15. If your study site includes all or part of a body of water, what is its name?

____

____

16. How much of the study site area is covered by your body of water?
Please check one. __ A lot (more than 30%) __Some (10-30%) __ A little (1-10%) __ None

17. Does your water body have water present all year, or just some fraction of the year?
Please check one. ___100% ____75%-99% ___ 50%-74% ___ less than 50%

18. Is your study site within 100 km of a very large lake (larger than about 5000 sq km), or a sea or an ocean? __ Yes __ No

If yes, in what compass direction is that lake, sea or ocean from your study

6. Soil

19. Which of the three traits below best describes your soil? Please check one. (If you are unsure, you may wish to read over the classification of soils in the *Soil Investigation.*)

___ Sandy (gritty) ___ Clayey (slippery when wet) ___ Rocky (rough)

7. Land Cover/Biology

20. Describe the land cover. (If you have already collected this information using the *Land Cover/ Biology Protocol,* please enter it here.) Please indicate approximately what percentage of the land is

_______ bare (rocks, sand or other soil with no vegetation)
_______ paved
_______ covered with buildings
_______ covered by grass, trees, and/or shrubs

If you wish, provide more information about the land cover at your study site here:

21. What animals live at the study site? Note: You may use whatever knowledge you have of the animals, or use any evidence of animals you may have observed at the study site.

22. Please describe here anything that is special or unusual about your study site:

Diagramming and Describing the Study Site for Others

Work Sheet–3: Student Self-reflection Log

Name:________________________________ Class: ______________________Date:___________

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you need help understanding. *You will not be graded on these responses.*

1. What have you learned about what makes the most effective diagram of your study site, that you feel confident about?

____

____

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____

2. What are you having trouble understanding about diagramming, or about your study site as a system?

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3. What would you like to know more about?

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Assessment Rubric: *LC4: Diagramming the Study Site for Others*

Collaborating to Develop a Class Diagram

	4	3	2	1
Collaborates to the ideas of others	Always participates fully; actively listens, suggests ideas, and responds ideas of others ideas of others	Usually participates fully; listens, suggests ideas, and responds constructively	Sometimes participates: listens and responds constructively to the	Rarely or never participates constructively to the

Assessment Rubric: *LC4: Diagramming the Study Site for Others*

Characteristics of an Effective Diagram

	4	3	2	1
Description of Effective Diagram	Fully describes, explains, and justifies opinions, on the basis of scientific accuracy, completeness, and clarity of communication	Adequately describes, explains, and justifies opinions, on the basis of scientific accuracy, completeness, and clarity of communication	Partially describes, explains, and justifies opinions, on the basis of scientific accuracy, completeness, or clarity of communication	Inadequately or incompletely describes and justifies opinions
Revisions to Own Diagram and to Characteristics of Effective Diagrams	Fully describes and justifies revisions	Adequately describes and justifies revisions	Partially describes and justifies revisions	Inadequately or incompletely describes and justifies revisions
Qualities Desired in Classmates for Collaboration	Describes several appropriate qualities, such as willingness to fully engage in the task, ability to contribute constructive ideas, and making constructive responses to the ideas of others	Adequately describes some appropriate qualities.	Partially describes some appropriate qualities	Inadequately or incompletely describes appropriate qualities

Assessment Rubric: LC4: *Diagramming the Study Site for Others*

Questions to Describe the Study Site

	4	3	2	1
Questions to Describe the Study Site	Suggests scientifically appropriate questions that fully and elaborately study site	Suggests scientifically appropriate questions that cover some aspects of study site	Suggests a few scientifically appropriate questions that cover few aspects of study site	Suggests no questions, or suggests scientifically inappropriate questions that inadequately cover the study site
Learning from Discussion and Comparison of Student Questions and Study Site Description Form	Demonstrates mastery of science concepts and careful thought about best means of describing the study site	Demonstrates satisfactory understanding of science concepts and adequate thought about best means of describing the study site	Demonstrates partial understanding of science; concepts and some thought about best means of describing the study site	Demonstrates superficial understanding of science concepts, and needs to think more deeply about best means of describing the study site

LC5: Comparing the Study Site to One in Another Region

Purpose

To deepen students understanding of the Earth as a system, and their appreciation for the value of diagrams as tools for both learning and communication, by having them work with diagrams of study sites from different regions

Overview

Earth's physical and environmental landscapes are diverse, and different conditions shape the interconnections among the components of a local Earth system in different ways. The class studies a diagram and description of a study site in a biogeographically different region than their own provided in this *Teacher's Guide*. Students analyze and compare the selected diagram and description with their own class diagram and description.

Student Outcomes

Students will be able to:

- Describe the different components and interconnections inherent in diagrams from other regions;
- Compare and contrast Earth system components and interconnections between their local site and a site in a different region.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Time

One 45-minute class period

Level

Middle, Secondary

Materials and Tools

One of four diagrams and the Site Description form from a region which is different from that of your school (provided, Figure EA-LC5-1a)

Preparation

None

Crosswalks to Other GLOBE Learning Activities

All of the following activities build the student's ability to compare the characteristics of Earth system study sites in different parts of the globe.

Hydrology Investigation: "Water, Water Everywhere! How Does It Compare?"

Students analyze GLOBE student data on the pH and temperature of different bodies of water, looking for trends over time.

Soil Investigation: Soil and My Backyard

Student explore soil and soil properties, discovering the variability of soils and how they are formed.

Soil Investigation: A Field View of Soil - Digging Around

Students discover that variations in the landscape, such as in slope, shade, and plants can affect soil properties, and that every soil is unique on every place on Earth.

Earth as a System Investigation: Seasons and Phenology: What Are Some Factors That Affect Seasonal Patterns?

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

Earth as a System Investigation Seasons and Phenology: How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?

Students use GLOBE visualizations to display student data on maps and explore seasonal changes in regional and global temperature patterns across the Earth. They learn that temperatures vary from one location to another around the world and that local latitude, elevation and geography affect seasonal temperature patterns.

Background

The basic processes that produce the interconnections among the various components of the Earth system are the same in all regions. However, since the geographic and environmental aspects of regions vary so dramatically, the processes that dominate the shaping of the different study sites will vary, as will the rate at which these processes proceed. As a result, the diagrams students develop from different regions may emphasize different portions of the Earth system and the interconnections between components.

One example of this difference is the contrast between a dry and a wet region. The diagram of a dry region with seasonal intense rain may emphasize that part of the hydrologic cycle which involves run-off, erosion, and soil type and soil moisture. The diagram of a wet region may emphasize evaporation, cloud cover and precipitation.

Another example of differences is the contrast between a continental (inland) environment and a maritime (near a large body of water) environment. The diagram from a continental environment may emphasize the interconnections between the land cover and the atmosphere, water and soil; while the diagram from the maritime environment may emphasize the influence of the large body of water on the local environment.

Even diagrams from the same types of regions may differ because of the differing interests of the students creating the diagrams. For example, students at one school might be more interested in the land cover at their study site, and their class diagram might emphasize that, while students at another school may be more interested in water quality, and their class diagram might emphasize that. It is important to keep this possibility in mind when comparing diagrams from different schools.

One can compare diagrams to determine how the environments of two schools are the same and how they are different, and how the components of the Earth system interact to produce those two environments.

What To Do and How To Do It

If you did not conduct the previous activity, begin with Step 1.

If you conducted the previous activity, begin with Step 2.

Step 1. Introduce the activity with a discussion of dramatic events or changes that have occurred in your local area.

Ask students to suggest events or changes, such as drought, flood, hurricane, fire, or loss of a particular habitat such as a wetland. Have students describe these events. What changed? What do people understand about it? What don't people understand? What do we still need to find out?

Explain that a new discipline of science has emerged, with which people attempt to understand changes like these by learning more about ways that parts of the Earth interact to make the whole. The discipline of Earth system science integrates all sciences that are concerned with the Earth: geology, hydrology, chemistry, botany and zoology, and meteorology.

People who study the Earth as a system are pioneers in this new discipline, and, as experts on their own local areas, GLOBE students can participate. Every area, every site is unique in certain ways. Ask students: How would you apply Earth system science to one of your study sites? How would you communicate the *system* aspect of your study site, its parts and how they interact, to another GLOBE school?

Step 2: Ask students to speculate about the geographic and ecological factors in other regions of the world that might shape an Earth system site differently from their own.

Introduce the activity by explaining that students will examine a study site diagram and a Study Site Description Form from another region of the world. Ask the students to suggest what might make a site in another region of the world different from their own site, in terms of the way it works as a system.

Prompt them with questions if necessary:

What about latitude and longitude?
What about elevation?
What about wind velocity and direction, topography, rainfall and all the other characteristics of a study site?
How would each of these factors influence components of the Earth system at that other site?

Step 3. Have students read the Student Background Reading and review the 4 diagrams from different regions provided by GLOBE.

Distribute the student background reading, *Study Sites and Diagrams from Different Regions*. Give students 5 minutes to read this material. Discuss any questions students may have.

Step 4: Distribute student copies and then have students compare a study site diagram from their own study site or a site similar to their own to one from a different geographic region.

Distribute students copies of:

- Class diagram developed by your students in *Activity LC4*, or the sample diagram that you select from those provided by GLOBE, that best represents your school's geographic area
- Class diagram from another region provided by GLOBE. Select one that is markedly different than your own. (You will distribute copies of the *Study Site Description Form* a little later in the activity, in Step 6.)
- *Comparing Diagrams from Different Regions Work Sheet*

- Assessment rubrics for this activity (You may want to share with students.)

Have the students work individually to compare the diagrams at first. In the next step, have them work together as a class.

On the *Comparing Diagrams from Different Regions Work Sheet,* ask your students to complete Part 1, *Looking at Science Concepts in the Diagrams.*

Step 5: Conduct a class discussion about differences and similarities between the science concepts in the two diagrams, and what the different concepts reflect about the characteristics of the different regions.

What, if any, are the differences in the science concepts that are represented?

Have a student list them on the blackboard.

Step 6: Have students explore reasons for any differences in concepts represented by the two diagrams. (Question 2 on the *Comparing Diagrams from Different Regions Work Sheet***)**

Distribute student copies of the *Study Site Description Form* from the other region different from your own. Explore with them how that description helps to explain any differences between diagrams.

To further understand the diagram from the other region, have students look at GLOBE data from that region, if available. Students may also use atlases and other sources of information about the geography and ecology of the region.

Step 7. Have students compare the styles of the two diagrams. (Question 3 of the *Comparing Diagrams from Different Regions Work Sheet***)**

Do the two diagrams communicate their content equally well? If not, which diagram communicates more clearly? Why?

What do your students like about the style of the other school's diagram?

Step 8. Ask students to write a comparison of the two diagrams.

The students should compare the diagrams as tools for communication about study sites as systems. They should:

1. describe differences between the content of the two diagrams and suggest explanations for them;
2. describe differences in style and their effectiveness for communication; and
3. identify features of the other region's diagram that students would recommend that the class incorporate into its own diagram.

Student Assessment

The *Comparing Diagrams from Different Regions Work Sheet*, can be used for assessment of student learning. An assessment rubrics for this *Work Sheet* is provided.

Further Investigations

Comparing GLOBE School Study Sites: Further Explorations

Students can obtain and analyze archived GLOBE data on two or more other GLOBE schools having selected study site characteristics that are different from their own. These can be found on the GLOBE Web site using the *Visualization Tools.* For example, they can select schools that have:

The same latitude as their own, and an elevation difference of 1,000 or 2,000 meters

The same elevation as their own, and a latitude that differs by 10, 20, 30, or 40 degrees

If your school is near a mountain range, a location on the side of it that is different from their own (east or west, to discover differences in rainfall)

Latitude and elevation the same as their own, but rainfall different

A climate that differs from their own: coastal vs. continental

Students can compare the GLOBE data from these schools and explain similarities and differences. (They should start with similarities, as these will probably be easier to explain.)

Study Sites and Diagrams from Different Regions

Student Background Reading

The place where you live and go to school is different in many ways from everywhere else. It has a special combination of characteristics such as climate, kinds of living things, soils, bodies of water (streams rivers, lakes, etc.), and land cover; elevation, and latitude and longitude. In this activity, you will look at diagrams and descriptions of study sites from other regions, and compare them with your own.

The diagrams in this activity represent the study sites as systems, in other words, as sets of parts, or components, and the processes that connect them. The components should be labeled: air, water, soil, and living things (or atmosphere, hydrosphere, pedosphere, and biosphere). They should be connected by arrows and phrases describing the processes that connect them.

You will also look at descriptions of those sites, on forms developed by GLOBE.

What similarities and differences between the diagrams and study sites will you find?

Looking at Components and Interconnections

The basic components and the interconnections among them are the same at nearly all sites: water, chemicals (such as carbon), and energy (such as heat) move among the four major components of the system (atmosphere, hydrosphere, pedosphere (soil), and biosphere). So you should find a lot of similarities in the components and interconnections represented in the other class's diagram. However, the *amounts* of water, chemicals, and energy in each component of the system, and the *rate* at which they move between the different components vary *a lot* among different regions of the Earth. Therefore, diagrams of different sites may emphasize different components and interconnections.

One example of differences might be seen in diagrams of study sites in dry vs. wet regions. In a dry region where it may rain during only one season of the year, students might emphasize erosion by wind and water in their diagrams. However, in a wet region where it rains or snows throughout the year, the students might emphasize more of the water cycle, showing evaporation, cloud cover and precipitation in their diagrams.

Another example of differences might be seen in diagrams of study sites in a tropical rain forest vs. a temperate forest. Students diagramming a rain forest site may emphasize the plants and their role as a storage place for nutrients, whereas students diagramming a temperate forest may emphasize the soil as a storage place for nutrients.

Looking at Style

What similarities and differences in style will you find when you compare the other class's diagram with yours? Diagrams can be more or less abstract (i.e. use realistic drawings or use symbols); they may use different kinds of symbols; and they may be complicated or simple — very decorative, or very plain.

Whatever their styles, all diagrams should be good communicators. In other words, they should be clearly drawn and labeled, and easy to understand.

Comparing Diagrams from Different Regions

Work Sheet

Name:_________________________ Class: ____________________Date:___________

Name and location of the other GLOBE school, whose diagram you are studying:

____

____

1. Compare the components and the interconnections among them, that are shown in the other school's diagram, with the components and interconnections that are shown in your class's diagram.

a. Does the other GLOBE school's diagram emphasize aspects of the study site that are different from the aspects emphasized in your diagram? Which aspects?

____

____

____

____

____

b. Explain why your think the two diagrams emphasize different aspects of interconnections among components of the study site.

____

____

____

____

____

2. Now look at the other class's *Study Site Description Form.* Does it help you to understand their diagram? If so, how?
   Be specific in your responses. Refer to specific information on the form and how it helps you to understand specific information in the diagram.

____

____

____

____

____

3. Compare the style of the other class's diagram with the style of your own. In other words, look at how the other class represented their components and interconnections. Does the diagram appear simple, or complicated? Did the other class use realistic drawings, or symbols?

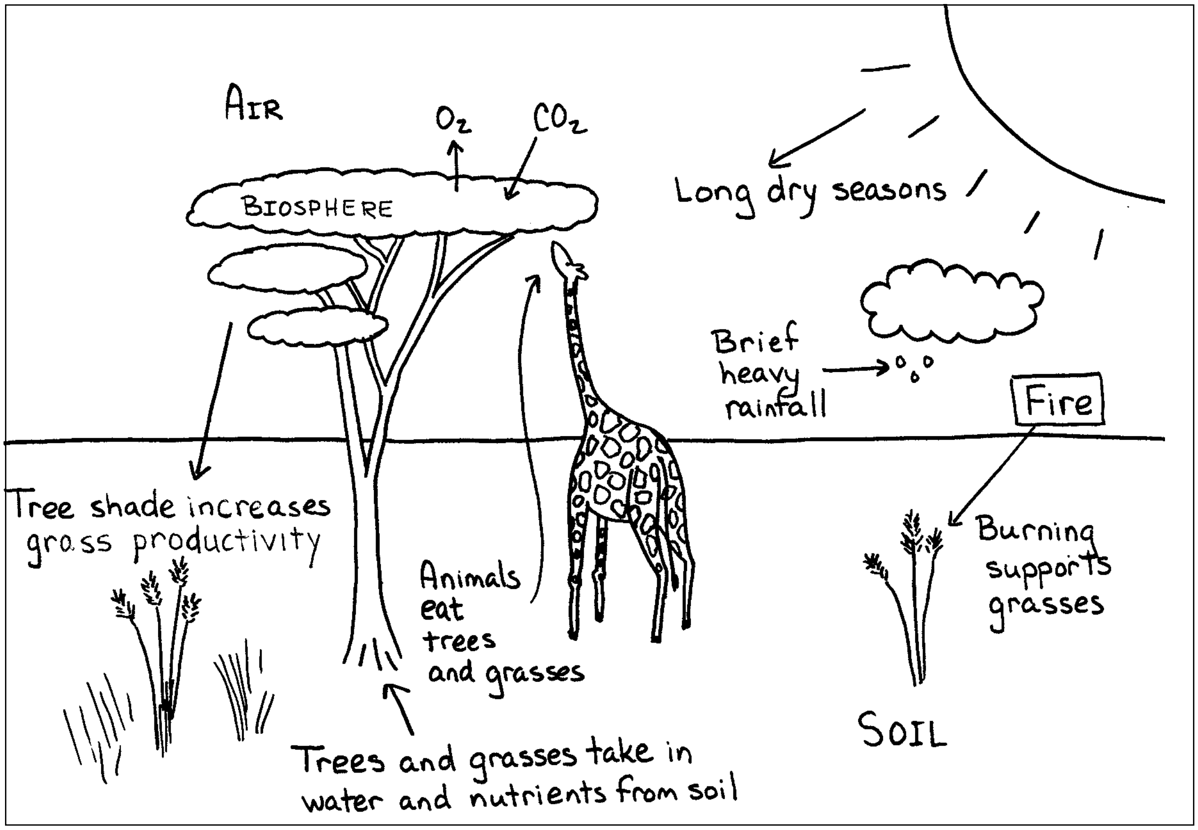
a. What is similar (if anything)?

b. What is different (if anything)?

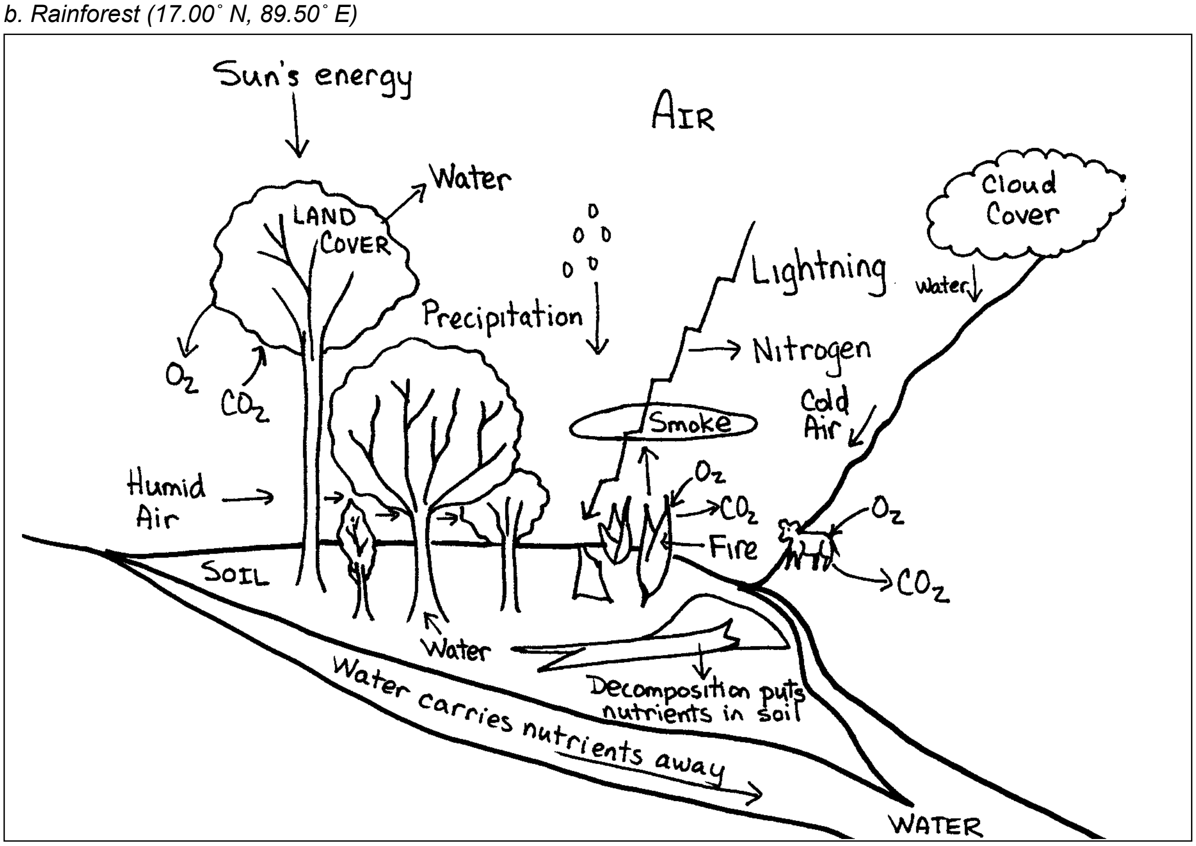
c. Which of the two styles do you think is better for communicating ideas about components and the interconnections among them, in a study site system? Why?

Figure EA-LC5-1: Sample class diagrams of study sites in different climatic regions: a) savannah, b) rainforest, c) marine/coastal, d) continental mid-latitudes (Reynolds Jr Sr High School covered bridge study site)

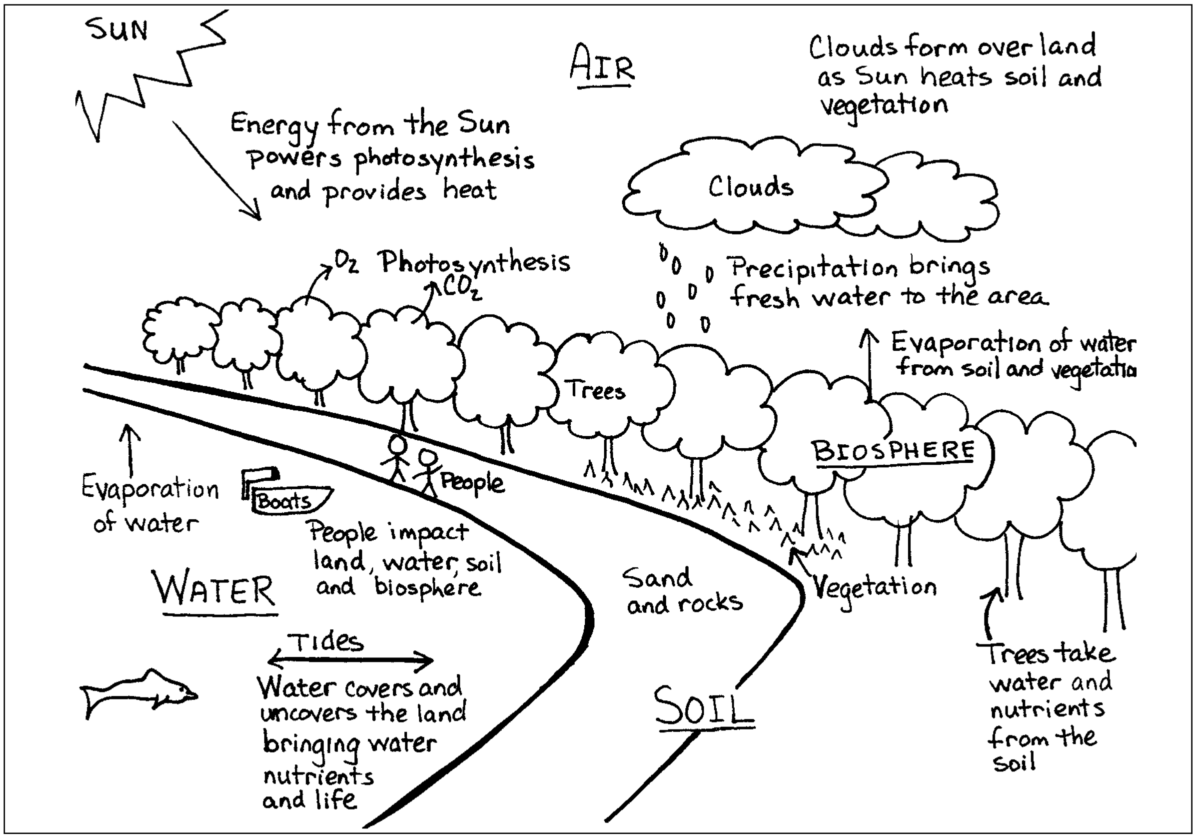
a. Savanna (13.40˚ N, 8.45˚ E)



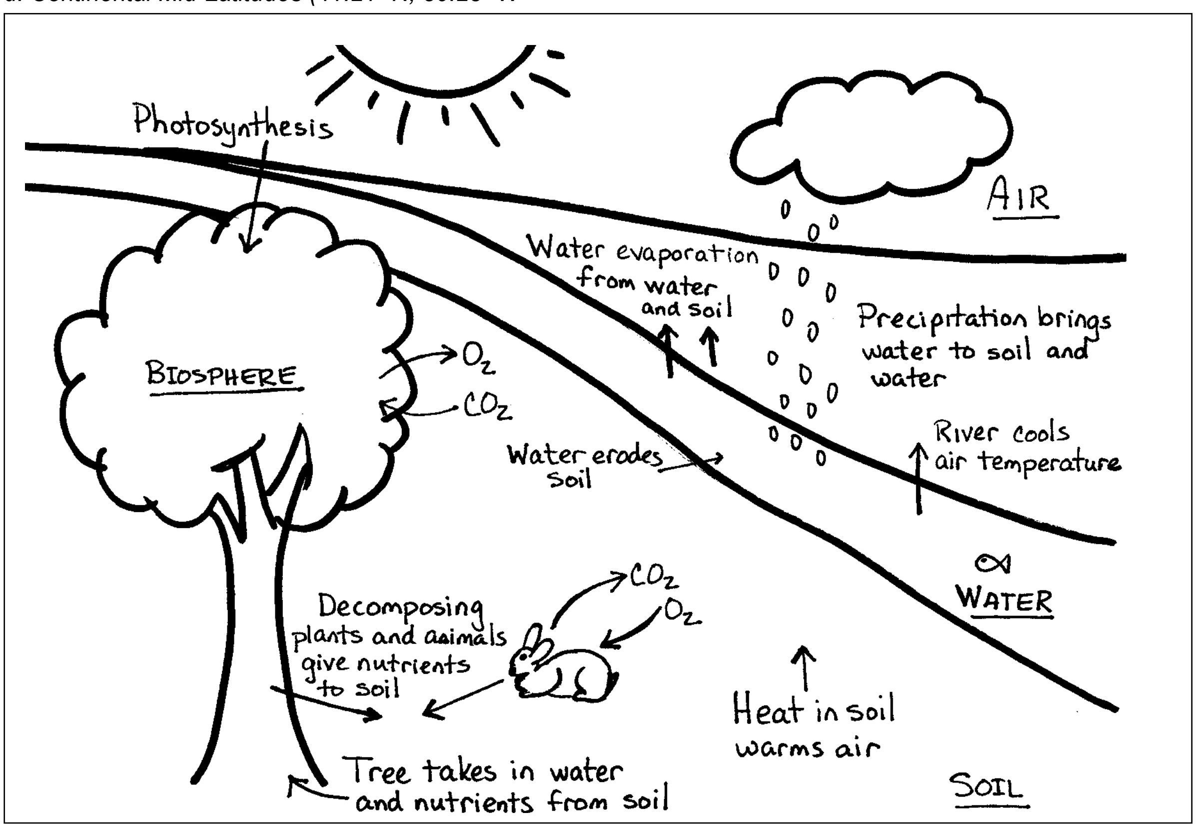
b. Rainforest (17.00˚ N, 89.50˚ E)



c. Marine/Coastal (41.00˚ S, 173.5˚ E)



d. Continental Mid-Latitudes (41.21˚ N, 80.23˚ W



Sample Study Site Description Form

Savannah (Figure EA-LC5-1a)

If you are comparing your class diagram with the sample diagram that represents a GLOBE study site in a savannah location, you can use this form to help you understand and interpret the sample diagram.

This is a sample form. The information on this form is accurate for a savannah location in Africa. It is not from a specific GLOBE school on that continent.

Today's Date: March 2, 2002 Season Depicted in Class Diagram: Spring

1. School Identification

1. School Name: (No School
2. School Address: Matameye, Niger

3. Teacher Name: (No Teacher Name)
4. Class Identification: (No Class Name)

(**Note:** Since a school may do this activity over a number of years with multiple classes, it is possible that there will be multiple diagrams for the same study site on the GLOBE web site. Therefore, please include here the name of the teacher who guided the development of the class diagram, and any other distinguishing notes about the class):

2. Study Site Location

5. Latitude: 13.40 degrees N
6. Longitude: 18.45 degrees E
7. Elevation (in meters): 102 m
8. Is your study site in the interior of a continent (more than 200 km from the coast)? X Yes __ No
9. Would you describe your site as urban, suburban, or rural? Please check one:

__ Urban (city environment, much of the land surface covered with concrete or other man-made material)

__ Suburban (many man-made structures separated by areas of open land, i.e. land not covered with man-made materials)

X Rural (farmland, mainly open land with few man-made structures)

3. Climate

10. Please check one:

__ Polar and subpolar (located between 60° latitude and the pole)

__ Mid-latitude (located between 30° and 60° latitude)

X Tropical and subtropical (located between 30° latitude and the equator)

11. What is the average precipitation your area gets in a year? Please give your response in cm. (You can get this information from an atlas, your local library, local civil engineer, or local government)
550 cm

12. Are there months of the year when your area usually gets more precipitation than during other months? X Yes ___ No

If yes, during what months does your area usually get more precipitation? June through September

4. Weather

13. Does your weather usually come from one particular compass direction during the season represented in your diagram of the study site as an Earth system? X Yes ___ No

If yes, what *general* direction (N, E, S, or W)? N

5. Water

14. Does your study site include part of a body of water, or is it within 100 m of one? X Yes ___ No

If yes, please indicate what type of water body it is by checking one below

If no, please go to Question 18.

X Stream
__ Canal
__ River
__ Pond
__ Lake
__ Bay
__ Ocean
__ Reservoir
__ Irrigation ditch
__ None

15. If your study site includes all or part of a body of water, what is its name?
Kori. The semi-permanent water way where irrigated agriculture is practiced. This year it is dried up.

16. How much of the study site area is covered by your body of water?
Please check one. __ A lot (more than 30%) __Some (10-30%) X A little (1-10%) __ None

17. Does your water body have water present all year, or just some fraction of the year?
Please check one. ___100% ___75%-99% ___ 50%-74% X less than 50%

18. Is your study site within 100 km of a very large lake (larger than about 5000 sq km), or a sea or an ocean? __ Yes X No

If yes, in what compass direction is that lake, sea or ocean from your study site (N, E, S, or W)? ____________

6. Soil

19. Which of the three traits below best describes your soil? Please check one. (If you are unsure, you may wish to read over the classification of soils in the *Soil Investigation.*)

X Sandy (gritty) ___ Clayey (slippery when wet) ___ Rocky (rough)

7. Land Cover/Biology

20. Describe the land cover. (If you have already collected this information using the *Land Cover/ Biology Protocol,* please enter it here.) Please indicate approximately what percentage of the land is

_______ bare (rocks, sand or other soil with no vegetation)
_______ paved
_______ covered with buildings
40% covered by grass, trees, and/or shrubs

If you wish, provide more information about the land cover at your study site here:

21. What animals live at the study site? Note: You may use whatever knowledge you have of the animals, or use any evidence of animals you may have observed at the study site.

Domestic- goats, cows, sheep, chickens, camels, horses Wild-snakes, pintard, rats, occasional monkeys

22. Please describe here anything that is special or unusual about your study site:

Sahelian village…. Fairly densely populated zone of Niger…near border with Nigeria, on a main road…area is sandy with red soil, made from weathered rock and heavy erosion and signs of desertification…from overfarming

Sample Study Site Description Form

Tropical Rain Forest Location (Figure EA-LC5-1b)

If you are comparing your class diagram with the sample diagram that represents a GLOBE study site in a rain forest location, you can use this form to help you understand and interpret the sample diagram.

This is a sample form. The information on this form is accurate for a rain forest location in Central America. It is not from a specific GLOBE school on that continent.

Today's Date: May 15 2002 Season Depicted in Class Diagram: Early Rainy Season

1. School Identification

1. School Name: (No School
2. School Address: Belize
3. Teacher Name: (No Teacher Name)
4. Class Identification: (No Class Name)

(**Note:** Since a school may do this activity over a number of years with multiple classes, it is possible that there will be multiple diagrams for the same study site on the GLOBE web site. Therefore, please include here the name of the teacher who guided the development of the class diagram, and any other distinguishing notes about the class):

2. Study Site Location

5. Latitude: 17.00 degrees N
6. Longitude: 89.50 degrees E
7. Elevation (in meters): 200 m
8. Is your study site in the interior of a continent (more than 200 km from the coast)? __ Yes X No
9. Would you describe your site as urban, suburban, or rural? Please check one:

__ Urban (city environment, much of the land surface covered with concrete or other man-made material)

__ Suburban (many man-made structures separated by areas of open land, i.e. land not covered with man-made materials)

X Rural (farmland, mainly open land with few man-made structures)

3. Climate

10. Please check one:

__ Polar and subpolar (located between 60° latitude and the pole)

__ Mid-latitude (located between 30° and 60° latitude)

X Tropical and subtropical (located between 30° latitude and the equator)

11. What is the average precipitation your area gets in a year? Please give your response in cm. (You can get this information from an atlas, your local library, local civil engineer, or local government)
130 cm

12. Are there months of the year when your area usually gets more precipitation than during other months? X Yes ____No

If yes, during what months does your area usually get more precipitation? May through October

4. Weather

13. Does your weather usually come from one particular compass direction during the season represented in your diagram of the study site as an Earth system? X Yes ____No

If yes, what *general* direction (N, E, S, or W)? E

5. Water

14. Does your study site include part of a body of water, or is it within 100 m of one? X Yes ____No

If yes, please indicate what type of water body it is by checking one below.

If no, please go to Question 18.

X Stream
__ Canal
__ River
__ Pond
__ Lake
__ Bay
__ Ocean
__ Reservoir
__ Irrigation ditch
__ None

15. If your study site includes all or part of a body of water, what is its name?
(No name)

16. How much of the study site area is covered by your body of water?
Please check one. __A lot (more than 30%) __Some (10-30%) X A little (1-10%) __None

17. Does your water body have water present all year, or just some fraction of the year?
Please check one. X 100% ____75%-99% ___ 50%-74% ___ less than 50%

18. Is your study site within 100 km of a very large lake (larger than about 5000 sq km), or a sea or an ocean? __ Yes X No

If yes, in what compass direction is that lake, sea or ocean from your study site (N, E, S, or W)? ____________

6. Soil

19. Which of the three traits below best describes your soil? Please check one. (If you are unsure, you may wish to read over the classification of soils in the *Soil Investigation.*)

___ Sandy (gritty) _X_ Clayey (slippery when wet) ___ Rocky (rough)

7. Land Cover/Biology

20. Describe the land cover. (If you have already collected this information using the *Land Cover/ Biology Protocol,* please enter it here.) Please indicate approximately what percentage of the land is

_______ bare (rocks, sand or other soil with no vegetation)
_______ paved
_______ covered with buildings
_80%_ covered by grass, trees, and/or shrubs

If you wish, provide more information about the land cover at your study site here:

21. What animals live at the study site? Note: You may use whatever knowledge you have of the animals, or use any evidence of animals you may have observed at the study site.

Too many to list. Many kinds of birds, tree frogs, scorpions, spiders; butterflies, beetles, ants; howler monkeys. Jaguars used to live here, and we think that sometimes a jaguar passes through. Other members of the cat family do live here all the time.

22. Please describe here anything that is special or unusual about your study site:

We have a rainy season that is May-October, and a drier season November-April.

Sample Study Site Description Form

Marine/Coastal Location (Figure EA-LC5-1c)

If you are comparing your class diagram with the sample diagram that represents a GLOBE study site in a marine/coastal location, you can use this form to help you understand and interpret the sample diagram.

This is a sample form. The information on this form is accurate for a marine/coastal location in New Zealand. It is not from a specific GLOBE school on that continent.

Today's Date: November 20, 1999 Season Depicted in Class Diagram: Spring

1. School Identification

1. School Name: (No School
2. School Address: Northern end of South Island, New Zealand

3. Teacher Name: (No Teacher Name)
4. Class Identification: (No Class Name)

(**Note:** Since a school may do this activity over a number of years with multiple classes, it is possible that there will be multiple diagrams for the same study site on the GLOBE web site. Therefore, please include here the name of the teacher who guided the development of the class diagram, and any other distinguishing notes about the class):

2. Study Site Location

5. Latitude: 41.00 degrees S
6. Longitude: 173.50 degrees E
7. Elevation (in meters): 20 m
8. Is your study site in the interior of a continent (more than 200 km from the coast)?
   ___Yes _X_No
9. Would you describe your site as urban, suburban, or rural? Please check one:

   __ Urban (city environment, much of the land surface covered with concrete or other man-made material)

   __ Suburban (many man-made structures separated by areas of open land, i.e. land not covered with man-made materials)

   X Rural (farmland, mainly open land with few man-made structures)

3. Climate

10. Please check one:

    __ Polar and subpolar (located between 60° latitude and the pole)

    X Mid-latitude (located between 30° and 60° latitude)

    __ Tropical and subtropical (located between 30° latitude and the equator)

11. What is the average precipitation your area gets in a year? Please give your response in cm. (You can get this information from an atlas, your local library, local civil engineer, or local government) ____cm

12. Are there months of the year when your area usually gets more precipitation than during other months? __X__Yes ____No

If yes, during what months does your area usually get more precipitation? May through August

4. Weather

13. Does your weather usually come from one particular compass direction during the season represented in your diagram of the study site as an Earth system? __X__Yes ____No

If yes, what *general* direction (N, E, S, or W)? W

5. Water

14. Does your study site include part of a body of water, or is it within 100 m of one? __X__Yes ____No

If yes, please indicate what type of water body it is by checking one below.

If no, please go to Question 18.

__ Stream
__ Canal
__ River
__ Pond
__ Lake
__ Bay
__ Ocean
X Reservoir
__ Irrigation ditch
__ None

15. If your study site includes all or part of a body of water, what is its name?

Cook Strait, between Tasman Sea and South Pacific Ocean

16. How much of the study site area is covered by your body of water?
Please check one. __A lot (more than 30%) X Some (10-30%) __A little (1-10%) __None

17. Does your water body have water present all year, or just some fraction of the year?
Please check one. X 100% ____75%-99% ___ 50%-74% ___ less than 50%

18. Is your study site within 100 km of a very large lake (larger than about 5000 sq km), or a sea or an ocean? X Yes __ No

If yes, in what compass direction is that lake, sea or ocean from your study site (N, E, S, or W)? N

6. Soil

19. Which of the three traits below best describes your soil? Please check one. (If you are unsure, you may wish to read over the classification of soils in the Soils Investigation.)

_X_ Sandy (gritty) ___ Clayey (slippery when wet) ___ Rocky (rough)

7. Land Cover/Biology

20 Describe the land cover. (If you have already collected this information using the *Land Cover/ Biology Protocol,* please enter it here.) Please indicate approximately what percentage of the land is

_______ bare (rocks, sand or other soil with no vegetation)
_______ paved
_______ covered with buildings
__40%__ covered by grass, trees, and/or shrubs

If you wish, provide more information about the land cover at your study site here:

Our study site is at the beach, so much of it is covered by sand and rocks.

21. What animals live at the study site? Note: You may use whatever knowledge you have of the animals, or use any evidence of animals you may have observed at the study site.

We have black-backed gulls, Caspian terns, and oystercatchers. On the beach, we have crabs and snails, cockles, urchins, sandhoppers, earwigs, and isopods, and many insects and spiders. Sometimes we see dolphin.

22. Please describe here anything that is special or unusual about your study site:

The weather can change very quickly here! We are on a small island in a great expanse of ocean. It is usually windy. The climate isn't extremely warm or cold. We have warm summers and mild winters.

Sample Study Site Description Form

Continental Mid-latitudes Location (Figure EA-LC5-1d)

If you are comparing your class diagram with the sample diagram that represents a GLOBE study site in a continental, mid-latitude location, you can use this form to help you understand and interpret the sample diagram.

This is a sample form. The information on this form is accurate for a continental, mid-latitude location in the United States. It is not from a specific GLOBE school on that continent.

Today's Date: November 1, 1999 Season Depicted in Class Diagram: Fall

1. School Identification

1. School Name: Reynolds Jr. Sr. High School
2. School Address: Greenville, PA 16154
3. Teacher Name: GLOBE Teacher
4. Class Identification: 4th period Earth Science

(**Note:** Since a school may do this activity over a number of years with multiple classes, it is possible that there will be multiple diagrams for the same study site on the GLOBE web site. Therefore, please include here the name of the teacher who guided the development of the class diagram, and any other distinguishing notes about the class):

2. Study Site Location

5. Latitude 41.21 degrees N
6. Longitude: 80.24 degrees W
7. Elevation (in meters): 350 m
8. Is your study site in the interior of a continent (more than 200 km from the coast)? X Yes __ No
9. Would you describe your site as urban, suburban, or rural? Please check one:

__ Urban (city environment, much of the land surface covered with concrete or other man-made material)

__ Suburban (many man-made structures separated by areas of open land, i.e. land not covered with man-made materials)

X Rural (farmland, mainly open land with few man-made structures)

3. Climate

10. Please check one:

__ Polar and subpolar (located between 60° latitude and the pole)

X Mid-latitude (located between 30° and 60° latitude)

__ Tropical and subtropical (located between 30° latitude and the equator)

11. What is the average precipitation your area gets in a year? Please give your response in cm. (You can get this information from an atlas, your local library, local civil engineer, or local government)

94.3 cm/yr

12. Are there months of the year when your area usually gets more precipitation than during other months? _X_ Yes ____ No

If yes, during what months does your area usually get more precipitation? September through November

4. Weather

13. Does your weather usually come from one particular compass direction during the season represented in your diagram of the study site as an Earth system? _X_ Yes ____ No

If yes, what *general* direction (N, E, S, or W)? SW-to-NW

5. Water

14. Does your study site include part of a body of water, or is it within 100 m of one? _X_ Yes ____ No

If yes, please indicate what type of water body it is by checking one below.

If no, please go to Question 18.

__ Stream
__ Canal
_X_ River
__ Pond
__ Lake
__ Bay
__ Ocean
__ Reservoir
__ Irrigation ditch
__ None

15. If your study site includes all or part of a body of water, what is its name?

Shenango River

16. How much of the study site area is covered by your body of water?
Please check one. _X_ A lot (more than 30%) __ Some (10-30%) __ A little (1-10%) __ None

17. Does your water body have water present all year, or just some fraction of the year?
Please check one. _X_ 100% ____ 75%-99% ___ 50%-74% ___ less than 50%

18. Is your study site within 100 km of a very large lake (larger than about 5000 sq km), or a sea or an ocean? __ Yes _X_ No

If yes, in what compass direction is that lake, sea or ocean from your study site (N, E, S, or W)? ____________

6. Soil

19. Which of the three traits below best describes your soil? Please check one. (If you are unsure, you may wish to read over the classification of soils in the *Soil Investigation.*)

___ Sandy (gritty) _X_ Clayey (slippery when wet) ___ Rocky (rough)

7. Land Cover/Biology

20. Describe the land cover. (If you have already collected this information using the *Land Cover/ Biology Protocol*, please enter it here.) Please indicate approximately what percentage of the land is

________ bare (rocks, sand or other soil with no vegetation)
________ paved
________ covered with buildings
__80%__ covered by grass, trees, and/or shrubs

If you wish, provide more information about the land cover at your study site here:

It's our Hydrology site , and it's right on the Shenago River

21. What animals live at the study site? Note: You may use whatever knowledge you have of the animals, or use any evidence of animals you may have observed at the study site.

Temperate zone forest animals and river animals

22. Please describe here anything that is special or unusual about your study site:

***Assessment Rubric: LC5:** Comparing the Study Site to One from Another Region*

Comparing Diagrams from Different Regions

	4	3	2	1
Comparison of Components and Interconnections in Diagrams	Compares components and interconnections shown on another GLOBE school diagram and own diagram specifically and with scientifically appropriate comments; comparison reflects careful analysis of diagrams	Adequately describes, explains, and justifies opinions, on the basis of scientific accuracy, completeness, and clarity of communication	Partially describes, explains, and justifies opinions, on the basis of scientific accuracy, completeness, or clarity of communication	Inadequately or incompletely describes and justifies opinions
Revisions to Own Diagram and to Characteristics of Effective Diagrams	Fully describes and justifies revisions	Adequately describes and justifies revisions	Partially describes and justifies revisions	Inadequately or incompletely describes and justifies revisions
Qualities Desired in Classmates for Collaboration	Describes several appropriate qualities, such as willingness to fully engage in the task, ability to contribute constructive ideas, and making constructive responses to the ideas of others	Adequately describes some appropriate qualities.	Partially describes some appropriate qualities	Inadequately or incompletely describes appropriate qualities

RC1: Defining Regional Boundaries

Purpose

To identify a region for study as a system, and to establish a list of characteristics and features useful for determining the boundaries of regional systems

Overview

Students discuss their current understanding of what Earth systems are and how they work, and consider how to identify the boundaries of a region for Earth system study. In small groups, they select a region for recommendation to the class, and they make a list of characteristics and features that can mark the boundaries of regional systems. After presentations by each group, the class chooses one region for study as an Earth system. Then they mark the boundaries of their chosen region on their Landsat image, topographic map, or other map.

Student Outcomes

Students will be able to,

- define “region” as an area which has similar features throughout;
- identify a specific region for study as an Earth system by finding boundaries; and
- describe the region’s boundaries so that others can find them on a map.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth’s surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth’s surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms’ functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Analyzing maps
Collaborating with classmates
Communicate results and explanations.

Time

One or two class periods

Level

Middle, Secondary

Materials and Tools

Landsat image of your school (provided by GLOBE)

Topographic maps and/or others such as vegetation, physical, soil maps of the region covered by the Landsat image (as available)

Preparation

Review the Landsat image and maps.

Make student copies. (See Step 1, Preparation.)

Prerequisite

Students must have some familiarity with Landsat images and maps for this activity.

Crosswalk to Other GLOBE Learning Activities

Hydrology Investigation: Model a Catchment Basin

Watersheds provide useful boundaries for study of the Earth system, and this activity introduces students to their watershed and how it works. It also builds their skills of interpreting maps and images, as they use these to construct a three-dimensional model of a watershed.

What to Do and How to Do It

Step 1. Preparation

Review the Landsat image and maps to find regions you may wish your students to identify.

GIS (Geographic Information System) images showing watersheds, soils, and vegetation and other land cover types can enrich the activity.

Identifying a Region

The region or regions you identify may be large or small. They should be larger than a study site, (defined by what one might see while standing in one place), and small enough for students to learn about them in a short period of time. If you need a specific size guideline, select an area that is about 5 km on a side.

Natural boundaries are best, but if by using only natural boundaries you have a region that is too large, use a man-made feature, such as a road.

Do not worry if regional boundaries cannot be sharply defined.

Because one of the great values of this module is the opportunity it provides for integration with the rest of your students' work on GLOBE, you may want your students to identify a region that includes one or more GLOBE study sites.

With your preparatory review of the Landsat images and maps, you will be able to gauge whether or not your students need help in interpreting them before they do this activity.

Make Student Copies

Section of the Landsat image that includes the regions you have selected for student investigation

GIS images (if you plan to use them)

Work Sheets:

- *Identifying a Region for Study*
- *Student Self-reflection Log: Identifying a Region*
- Assessment rubric for this activity (You may want to share with students.)

Step 2. Explain the purpose of the activity: to better understand the Earth at the regional scale by viewing it as a system.

Explain that students will explore a new way of looking at the Earth – that is, as one system, a set of interconnected parts or components.

If you have any question about your students' grasp of what a system is, you might wish to take a few minutes to have each of them write a definition and share it in discussion with the class.

Advanced students should need little help here. Beginning students may need to consider some familiar systems. You can elicit their ideas about what some systems might be: a car, a social group, a sports team, the human body. You might draw a simple diagram of such a system on the board or on an overhead, or ask students to do that for the class.

Explain to students that they will work with their GLOBE Landsat image, maps, and possibly other materials to identify and delineate the boundaries of a region for study as a system. In the next activity, they will consider the inputs and outputs of that regional system, i.e. what enters and leaves it such as water, soil particles, living things, energy, and chemicals.

Make it clear to students that there are no right or wrong answers in this activity, and there is no one region that students will be expected to identify. What is important is for them to improve their skills at analyzing geographic information, at viewing regions as systems, and at justifying whatever choices of regions they make.

Step 3. Have the class focus on and describe the area around the school, or a selected GLOBE study site, or other sites that may be familiar to them.

Distribute the student copies of the Landsat image and any topographic maps or other maps of the area that you have. Look at the image and maps with students, and help them interpret what they see. What are the general features of the area? Discuss them. What can you conclude about land cover types, vegetation, and soils from the maps? Can you determine where all the water at the site comes from, and where it goes?

Explain that a region should have some features that are homogeneous throughout, and boundaries that can be described. Do any regions become apparent to the class?

Step 4. Ask students for a definition of "region."

Discuss their suggestions.

A region can be defined as a geographic area that has some consistent features or characteristics throughout. Regional boundaries are places where those features or characteristics change. Regions can be large or small.

Step 5. Ask students what characteristics and features one might use to define a particular region.

If they need prompting, suggest they consider the characteristics listed here.

Bodies of water: streams, canals, rivers, ponds, lakes, or an ocean
(A watershed makes an effective region for study as an Earth system.)
Topographic features such as mountains, plateaus, or valleys
Vegetation types: Forest, meadow, wetland, desert
Soil types
Soil moisture
Dams
Roads, bridges, and other areas of human development (homes, office buildings, factories, and shopping centers) if they are large enough to affect inputs and outputs to the region
Political boundaries such as county or state lines
Parks

Have one student record a class list of characteristics on the board.

Step 6. Distribute the *Identifying a Region for Study Work Sheet.* **Organize students into small groups, and ask them to identify a specific region to recommend to the class for study in the next activity.**

Students should keep in mind the purpose of defining a region for Earth system study in this set of activities, because, in the next activity, they will look at the region as a system of interacting components and will explore what enters the system and what leaves it. The regional boundaries they establish now will have much significance in the next activity, as students attempt to identify what crosses those boundaries.

Tell them that each group will be asked to describe its chosen region to the class and to justify the choice.

Request that each group designate a spokesperson.

Step 7. Have student groups present and justify their chosen regions.

Explain that the class will now choose one region to study as a system. The region the class ultimately chooses is of less importance than the process of student thinking about regions as systems, and of their collaborative work with each other. If you conduct *Activity RC2,* your students will have an opportunity to discover how well their characteristics and features for regional boundaries work when they consider specific inputs and outputs to the region as an Earth system.

Step 8. Help the class reach consensus on which region would work best for study as a system.

If the class has difficulty reaching consensus, encourage them to look at how clearly a given region is defined by its boundaries, and how feasible and interesting it might be to study a particular region as a system with inputs and outputs.

Step 9. Have students draw the boundaries of the class region on their copies of the Landsat image or map.

Have students keep their copies of the map, or collect them for safekeeping until the next activity.

Step 10. Collect the *Identifying a Region for Study Work Sheet,* **and distribute the** *Student Self-reflection Log: Identifying a Region Work Sheet* .

The *Self-reflection Log* can be completed either in class or as homework.

Student Assessment

These student products can be used for assessment:

Work Sheets

Identifying a Region for Study

Student Self-reflection Log: Identifying a Region

Copies of maps on which students draw the boundaries of their group's selected region

An assessment rubric covering the first work sheet, (group presentations and maps) is provided. Students' responses to the questions on the *Self-reflection Log* cannot be quantified, yet they play a special role in student learning. Students experiencing confusion or other problems with the topic may be more comfortable expressing themselves on the work sheet than in front of the whole class.

Further Investigations

Earth System on Foot

Take students to explore the selected Earth system region. Visit the areas that students identified as regional boundaries, and invite them to reconsider the appropriateness of those boundaries. Give them an opportunity to modify their list of characteristics and features.

Land Management with Earth System Science

Ask land management professionals how they define regions for their work, what criteria they use, and how effective they think those criteria are. Find out which land management issues are being addressed on the basis of watershed boundaries, and why.

Usefulness of Diagrams at Different Scales

For students who have completed *Activity LC2* or *LC4*: Ask students to predict how well their diagrams of the local study site will apply to the regional scale, without looking again at those diagrams. Then have them retrieve the diagrams, evaluate how well they apply to the regional scale, and complete a short written report on their evaluation.

As mentioned earlier in this activity, the regional scale is geographically larger than the local scale, but many of the processes that shape the Earth system act in similar ways over a range of scales.

Identifying a Region for Study
Work Sheet

Name:________________________________ Class: ______________________Date:___________

1. What is a region? Write your definition here.

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2. With the other members of your group, find a region to recommend to the class for study as a system. Describe it here.
   Remember that you want a region you can look at in terms of what goes in and comes out of it (inputs and outputs).

   a. What features or characteristics are you using to identify your region? Why?

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   b. How will you describe your region to the class? List the geographic landmarks that will help you identify the full circumference of the region's boundaries – north, south, east, and west. You can use latitude and longitude lines, if necessary.

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Identifying a Region

Work Sheet-2: Student Self-reflection Log

Name:______________________________ Class: _____________________Date:__________

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you need help in understanding. <u>You will not be graded on these responses</u>.

1. What have you learned about identifying regions that you feel confident about?

2. What are you having trouble understanding about regions?

3. What more would you like to know about the region you have identified?

Assessment Rubric: RC1: *Defining Regional Boundaries*

Identifying a Region for Study as a System

	4	3	2	1
Definition of Region	Defines a region as an area with some features that are heterogenous (the same) throughout; features are scientifically appropriate	Defines region as an area that is different from others around it	Defines region as a particular area	Has not yet defined region
Presentation of Region Selected	Fully and clearly describes specific features that are heterogeneous throughout the area,	Partially describes features that are heterogeneous throughout the area,	Partially describes features that are heterogeneous throughout the area	Has not yet attempted to justify selection of region
Boundaries Marked and Described	Clearly marks full circumference of boundary on map, and describes it with specific geographic place names and/or latitude/longitude lines	Clearly marks full circumference of boundary, and describes it in general terms	Marks and describes some of boundary in general terms	Incompletely and vaguely describes boundaries

RC2: Effects of Inputs and Outputs on a Region

Purpose

To identify what enters and leaves the regional system, and how changes in the input or output of one component can affect other components

Overview

Using the region they identified for study in *Activity RC1,* or a region identified by the teacher for this activity, students draw an imaginary box around the region. The box includes what is above the Earth's surface (the atmosphere), and what is below (the soil, or pedosphere). Using their existing knowledge, they discuss and list inputs and outputs of the region, prompted by guidance questions from the teacher if necessary. Next, students generate and explore "what if" scenarios. (e.g. What if the water flowing into the region were reduced by half? What if it were doubled? What if the land cover upstream were removed, or changed from forest to cropland? What if no birds moved across the region's boundaries?) Students learn to ask such provocative questions and to make thoughtful predictions of ways in which changing one component might affect the properties of others in the regional system. Prompted by guidance questions, they write about what they have learned.

Student Outcomes

Students will be able to:

- Identify some scientifically appropriate inputs and outputs of a system at the regional scale;
- Predict how changes in the input or output of one component of a system might affect other components, reflecting the concept that parts of a system shape each other through their interactions.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Identify answerable questions.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

One or two class periods

Level

Middle, Secondary

Materials and Tools

Landsat image of your school (provided by GLOBE)

Topographic maps and/or other such as vegetation, physical, soil maps of the region covered by the Landsat image, (as available)

Preparation

This activity will be most meaningful if your students have completed *RC1*. If you did not conduct *RC1*, read Steps 1 and 2 of What To Do and How To Do It in this activity.

Gather Landsat images and maps.

Make student copies (See Step 1. Preparation.)

Prerequisites

None

What to Do and How to Do It

Step 1. Preparation

If you did not conduct *Activity RC1*, identify a region for study as an Earth system, and draw its boundaries on the Landsat image provided by GLOBE, or on a map.

The region you identify may be large or small. It should be larger than a study site, (defined by what one might see while standing in one place), and small enough for students to learn about it in a short period of time. If you need a specific size guideline, select an area that is about 5 km on a side.

Natural boundaries are best, but if by using only natural boundaries you have a region that is too large, use a man-made feature, such as a road. Do not worry if regional boundaries cannot be sharply defined.

Because one of the great values of this set of activities is the opportunity it provides for integration with the rest of your students' work on GLOBE, you may want your students to identify a region that includes one or more GLOBE study sites.

Make Student Copies

Work Sheets:

– *Inputs and Outputs of a Regional System*

– *Predicting Changes to the Regional System*

– *Student Self-reflection Log: Regions as Systems*

Landsat image or map on which you draw the boundaries of the region for study

Assessment rubrics provided for this activity (You may want to share with students.)

Step 2. Introduce the activity.

If you conducted *Activity RC1,* have students refer to their copies of the Landsat image or map on which they drew the boundaries of the class region.

If you did not conduct *Activity RC1,* distribute student copies of the Landsat image or of a map showing the region you have identified for this activity.

Explain to students that in this activity, they will look at a region for study as a system: they will consider what enters and leaves the system — its inputs and outputs.

Step 3. Ask students to put an imaginary box around the region and, using their current knowledge, consider what enters and leaves the box.

Instruct students to imagine a box that includes not only the surface of the Earth, but also what is above (atmosphere) and what is below the surface (the pedosphere or soil).

Write the names of these four major components of Earth systems on the board:

Atmosphere — air, clouds, and precipitation (rain, snow, hail)
Hydrosphere —bodies of water, such as streams, canals, rivers, ponds, lakes, and oceans; also ground water
Pedosphere — soil
Biosphere — living things

Conduct a class discussion about a region's inputs and outputs – what enters and leaves the system.

The purposes of this discussion are to make sure students understand what inputs and outputs are, and to stimulate their thinking about systems. In the next step, they will be asked to make their own lists of inputs and outputs of the region.

Ask students to be as specific as possible in their responses. For example, they might mention storms coming to the region from the direction of another city (naming the city); garbage being trucked to a particular landfill in another region; pine seeds from a specific forest (naming the forest and even the species of pine if possible) outside the region blowing into a particular meadow; fish swimming upstream (naming the stream) across the regional boundary to spawn.

Assure students that whatever they know about the water cycle, the energy cycle, and the chemical cycle can be applied to this question, as water, energy and chemicals move among the different parts of the Earth system. Remind students that people are also part of the Earth system.

This activity can make wonderful use of students' existing knowledge in a range of subject areas: meteorology, chemistry, biology, ecology, geology, and others. Students may need some prompting from you in order to draw upon that knowledge.

Step 4. Distribute the Student Work Sheet *Inputs and Outputs of a Regional System,* **and ask students to complete it.**

Have students work in small groups for about 10 minutes as they complete the work sheet.

If they wish, students can include general quantities — a little, some, or a lot — for any given input or output.

Step 5. Compile a class list of inputs and outputs of the region.

Ask students to share inputs and outputs from their lists, and have selected students compile a class list on the board. If the class needs prompting, refer to the list of possibilities in the following section, *Teacher Guidance.*

Suggest that students make notes about what they are thinking and learning. They can use their notes later in a summary about what they have learned.

Teacher Guidance

If necessary, prompt students with *concepts* from this list.

You may add to this list if you wish!

Students should be as explicit as possible in their responses, specifying geographic names and identifying any plant and animal groups.

Inputs

Atmosphere

Air currents from the southwest (or other appropriate direction)

Heat or cold, rain or snow from other regions, carried by winds

Dust carried by the wind

Nitrogen from the air, taken into plants

Heat and light from the sun

Hydrosphere

Water from upstream

Sediment eroded from stream banks upstream

Biosphere

Seeds carried by birds and other animals

Sediment eroded from stream banks upstream

Nitrogen from the air, taken into plants

Outputs

Atmosphere

Air currents to the northeast (or other appropriate direction)

Water in the air that may have been evaporated from the surface, moving from inside the region to outside it

Heat or cold carried by winds, movement of air masses

Water evaporating into the atmosphere

Heat radiating back into space

Light reflected back into space

Hydrosphere

Water flowing downstream

Sediment and other substances carried by the water

Leaves falling into stream and carried away

Biosphere

Animals crossing regional boundaries

(Students should think about specific animal groups one at a time, both vertebrates and invertebrates)

Animals eating within the region and leaving the region

Seeds carried away by birds and other animals

Leaves falling into stream and carried away

Step 6. Ask students to generate "what-if" questions about changes in the amounts of specific inputs and outputs, and to predict answers to those questions.

Distribute the *Predicting Changes to the Regional System Work Sheet* .

Have students generate a list of questions, and then ask for predictions. Make sure that the students' questions and predictions deal with only one change to the system at a time.

Following are some questions with categories of change that students might consider:

What if the region got half as much rain as it does now? (Change in atmosphere)
What if the region got twice as much rain as it does now? (Change in atmosphere)
What if a dam were built upstream? What if one were built downstream? (Change in hydrosphere)
What if there were no water at all entering the region? (Change in hydrosphere)
What if the prevailing wind changed direction? (Change in atmosphere)
What if the number of people living in the region were halved? What if it were doubled?
(Change in biosphere)
What if all people left the region? (Change in biosphere)
What if no birds flew into the region? (Change in biosphere)

What if different species (kinds) of birds flew into the region? (Change in biosphere)

What if the meadow became a forest? (Change in biosphere)

What if the meadow became a shopping center? (Change in biosphere and pedosphere)

What if there were no soil? (Change in pedosphere)

What if the imaginary box around the region were impermeable and nothing could enter or leave it? (Change in all components)

Instruct students to state their predictions by describing changes to the four major components of the system: atmosphere, hydrosphere, pedosphere, and biosphere. In other words, for each "what if" question, how would that change influence the properties of the soil? How would it influence the properties of the hydrosphere? How would it affect the properties of the living component of the region? How would it affect the properties of the atmosphere?

The critical concept here is that changing the properties of one component of the system alters the properties of other components.

As in the last activity, there are no "right" questions or predictions. There are only reasonable, thoughtful, well-informed ones. The importance lies in students enhancing their awareness and perception of the region as a system.

Step 7. Have the class decide: Is the region an open system or a closed system? Why?

This question is significant not only when one considers the region as an Earth system, but also when one considers systems in general. An *open system* is one that exchanges matter and/or energy across its boundary. A *closed system* is one that does not exchange any matter across its boundary.

Given their work with inputs and outputs of their region, students should be able to say that their region is an open system. A great deal enters and leaves it.

Step 8. Either in the course of class work or as a homework assignment, have students complete the *Student Self-reflection Log: Regions as Systems Work Sheet.*

Student Assessment

Three *Work Sheets* can be used for student learning assessment:

- *Inputs and Outputs of the Regional System*
- *Predicting Changes to the Regional System*
- *Student Self-reflection Log: Regions as Systems*

Assessment rubrics are provided for the first two work sheets.

Inputs and Outputs of a Regional System

Work Sheet–1

Name:__________________________________ Class: ________________________Date:____________

Make a list of the inputs and outputs of a region defined by your class during the previous activity, or of another region identified for this activity by your teacher. What enters and leaves the region?

Think about these parts, or *components,* of the Earth system and the processes that connect them:

1. Air, clouds, and precipitation (rain, snow, hail): <u>Atmosphere</u>
2. Water in streams, canals, rivers, ponds, lakes, and oceans; also ground water: <u>Hydrosphere</u>
3. Soil: <u>Pedosphere</u>
4. Living Things: <u>Biosphere</u>
5. Cycling of water, chemicals and energy

What is carried by water? What is carried by air? What moves through the ground? What do animals carry? What do people carry?

Inputs - *attach additional sheet if necessary*

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Outputs - *attach additional sheet if necessary*

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Predicting Changes to the Regional System

Work Sheet–2

Name:______________________________ Class: ____________________Date:__________

Instructions

1. Think of some "what-if" questions about changes to specific inputs and outputs of the region; write them down in the space below and on the next page. Use extra paper if needed.
2. For *each* of those what-if questions, make a prediction. How will that change affect the other components (atmosphere, hydrosphere, pedosphere, and biosphere) of the region?

Tips

- Make sure your questions and predictions deal with only one change to the system at a time.
- As you did on the Student Work Sheet, *Inputs and Outputs of a Regional System,* write your predictions in terms of four major components of the Earth system (atmosphere, hydrosphere, pedosphere (soil), and biosphere). How might the change affect the atmosphere? How might it affect the biosphere (living things)?
- Be prepared to defend any predictions you make on the basis of scientific knowledge.

Example: What if *the stream coming through the region was dammed up before the water entered the region?*

Then I predict

1. The plants in the region would die and the animals would leave due to lack of water. (biosphere)
2. The region would be dryer because there would be less water both in the soil and atmosphere. (pedosphere and atmosphere)
3. The stream bed would dry up and the fish would die. (hydrosphere, biosphere)

Write your questions and predictions below. Use separate paper if you run out of space to write.

What if…this change took place:

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Then I predict that this might happen to the other components of the system:

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What if…this change took place:

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Then I predict that this might happen to the other components of the system:

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What if…this change took place:

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Then I predict that this might happen to the other components of the system:

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What if…this change took place:

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Then I predict that this might happen to the other components of the system:

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Regions as Systems

Work Sheet-3: Student Self-reflection Log

Name:______________________________ Class: ____________________ Date:__________

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you need help in understanding. You will not be graded on these responses.

Instructions

1. Summarize what you have learned about the region as a system during this activity (and the previous one, if your class completed it). Use these questions to prompt your thinking:

a. How has your study of the region helped you understand it better?

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b. What did you discover about this region that you did not know before?

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c. What questions do you have now about the region?

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2. *For students who have completed Activity RC1, Defining Regional Boundaries.* In that activity, you identified a region to study as a system, and delineated its boundaries according to certain features and characteristics. Now that you've worked with that region as a system, what do you think of your choice? Did the area you chose work well as a regional system? Why or why not? Please explain here. ____

Assessment Rubric: RC2: *Effects of Inputs and Outputs on a Region*

Inputs and Outputs of a Regional System

	4	3	2	1
List of Inputs and Outputs Includes energy,	Lists 15 or more scientifically appropriate inputs and/or outputs. Includes energy, chemicals, and water; mentions carbon, nitrogen, and heat.	Lists 10 or more scientifically appropriate inputs and/or outputs chemicals, or water.	Lists 5 or more scientifically appropriate inputs and/or outputs.	Lists 2 or fewer scientifically appropriate inputs and/or outputs.

Assessment Rubric: RC2: *Effects of Inputs and Outputs on a Region*

Predicting Changes to the Regional System

	4	3	2	1
Questions	Poses 4 or more scientifically interesting and reasonable questions about changes to the inputs and outputs of the region; some questions are particularly interesting	Poses 3 or more scientifically interesting and reasonable questions about changes to the inputs and outputs of the region	Poses 2 or more reasonable questions about changes to the region, but does not seem to understand concept of inputs and outputs	Poses one or no reasonable or scientifically interesting questions
Predictions	Makes predictions for all questions posed, reflecting considerable thought about ways that parts of a system shape each other through their interactions. Predictions are based on sound scientific principles	Makes predictions for most questions posed, reflecting some thought about ways that parts of a system shape each other through their interactions. Most predictions are based on sound scientific principles	Makes some reasonable predictions, reflecting a little thought about ways that parts of a system shape each other through their interactions	Bases predictions only partially on sound scientific principles. Does not make any predictions based on sound ecological and physical principles.

GC1: Your Regional to Global Connection

Purpose

To identify specifically how one's own region is connected with others, and to discover the interconnected nature of the Earth's regions as systems

Overview

Students brainstorm about the nature of connections between their region and others, across oceans and on different continents. On a black-line map of the world, they trace possible pathways of water and wind currents from their part of the continent to other continents, and identify what the wind and water carry. Then they write about the possible effects of activities in other regions on their region, and the possible effects of activities in their regions, on others.

Student Outcomes

Students will be able to,

- trace pathways of wind and water on a world map to and from their region, and across an ocean to other parts of the Earth;
- describe specifically how their region is connected as a system to others across the Earth by identifying what their wind and water carry;
- write about what activities in their region might affect other regions, and what activities in other regions might affect theirs; and
- define *open system* and *closed system*.

Science Concepts

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Reading and interpreting maps

Making maps

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

One class period

Level

Middle, Secondary

Materials and Tools

Map of study region and surroundings

Map of the world

Maps of major wind and ocean currents, (Figures EA-GC1-2 and EA-GC1-3) provided by GLOBE in the *Teacher's Guide*

Colored pens or pencils for students to distinguish between wind and water on their work sheets

Preparation

Identify a study site.

Make student copies.

-*Work Sheets*

-Three kinds of maps

Display a variety of maps

Prerequisites

None

Background

Paths of Ocean Currents and Wind Patterns

It is important to understand that the maps provided for identifying ocean currents and wind patterns show average paths over an extended period of time (such as an average of many consecutive Januarys). It is very difficult to trace the exact path of a particular parcel of air or ocean water and anything it might contain. In the atmosphere, the motion of a parcel of air is influenced by a variety of factors, such as its location with respect to the location of the center of low or high pressure, and its altitude. In addition, the motion can be a composite of a lot of different motions. For example, weather patterns (low and high pressure systems), tend to move from west to east in mid-latitudes. However, the air circulates around that center, so that at times an air parcel might be going in exactly the opposite direction from the direction that the system as a whole is moving. The ocean functions the same way. There are major currents, but within those currents there can be eddies which move water in a different way on a smaller scale.

As students of the oceans and atmosphere, we want to look at paths of ocean currents and wind patterns over extended periods of time. For our studies, the span of time should be greater than the life of any single storm system in the atmosphere (about 4-5 days), and longer than the life of an eddy in the ocean (generally longer than a month). In addition, the paths we identify are only approximate, and the actual path may differ considerably from one time period to another. However, these patterns contain important information as to how the Earth system behaves *on average*.

What are Open and Closed Systems?

An open system is one that exchanges material and/or energy across its boundary. A closed system is one that does not exchange any material or energy across its boundary. An almost closed system is one in which there is very little exchange. The Earth system at the global scale is an almost closed system. For Earth system science, the only significant thing that crosses the boundary between Earth and space is energy – incoming energy from the sun and the thermal radiation (heat) emitted by the Earth into space. All other materials remain for the most part within the Earth system. There is some gas lost to space and some incoming particles but the amount is extremely small.

What to Do and How To Do It

Step 1. Preparation

Identify a study site and region from which students will trace paths of wind and water. If you have not already identified an Earth system study site or a Hydrology study site for this module, the schoolyard itself will suffice.

Make Student Copies

- *Tracing Water Currents and Winds*
- *Global Pathways of Wind and Water*
- Assessment rubric for this activity (You may want to share with students.)

Make student copies of these three kinds of maps:

- Map of study region and surroundings (perhaps several counties or provinces)
- Map of the world
- Maps of major wind and ocean currents, provided by GLOBE

Display where students can see them and any other available maps of the continent and the world.

Obtain any available information about local wind currents and waterways. You may choose to assign this task as a special research project to one or more students. Ask the class to brainstorm about specific ways in which their region is connected to others, across oceans and to different continents.

Step 2. Ask the class to brainstorm specific ways in which their region is connected to others, across oceans, and to different continents.

Distribute copies of the map of the study region and surroundings. Identify and describe the region of study for students. Ask students to use their existing knowledge to suggest what crosses regional boundaries.

If you have conducted *Activity RC1,* students will already be familiar with the region they have identified for Earth system study as a class. If they completed *Activity RC2,* they can recall their work on inputs and outputs of the region as a system.

Student responses may include heat and light, wind and water, and substances and organisms that are carried by wind and water. Encourage students to be specific in their answers. Which bodies of water? Which substances? Which groups of organisms?

Ask students to describe how far and where these components go. Do they leave the state? Do they leave the continent? Do they cross an ocean?

Much of this may be conjecture for students. The more accurate and specific they can be, the better. However, what is most important is for them to begin thinking in terms of specific ways in which their regional system connects with other regional systems. The output of one system becomes the input of another.

Step 3. Review the regional and continental maps with the class, and guide them in tracing the flow of water into their study region, then downstream from their region to connecting regions, and then beyond, to an ocean.

Distribute copies of the *Tracing Water Currents and Winds Work Sheet,* copies of the world maps of average ocean currents and world maps of average winds. See Figure EA-GC1-1 and EA-GC1-2 and copies of your regional and continental maps.

Ask the class to trace the flow of water from their study region. Start upstream at its source, then move downstream through their region to an ocean, noting the names of bodies of water and the regions through which it passes. Note where the water connects on the continental scale.

If students are familiar with the concept of a watershed, and if the region selected for Earth system study is a watershed, this step can be expanded to include students finding their "watershed address." See *Further Investigations.*

Step 4. Have students draw the pathways of their region's air and water on their work sheets: from where it meets an ocean, across that ocean to other continents, to around the globe.

Students may want to use pencil at first; then they can use different colored pens or pencils to distinguish wind direction and water currents from each other.

On their work sheets, they should also write the geographic names of regions along the water's pathway.

Step 5. Review the map of winds with the class, and discuss the paths of wind into and out of their region.

Step 6. Have students draw the pathways of wind on their work sheets, both into and out of the region.

As they did for water pathways, students should write the geographic names of regions through which the wind passes.

Step 7. Discuss the implications of global wind and water circulation patterns for your region.

Conduct a class discussion on the issue. Ask students to consider wind. What are the regions from which wind blows into your region? What might it carry (dust, insects, tiny seeds, particles of soil, smoke, air masses of cooler or warmer temperatures, moisture)? Toward what region does the wind generally blow from your region? What might it carry?

Ask students to consider water. What substances and organisms are carried into and out of your region by water?

Now have students speculate: What activities in other parts of the globe could affect your region? What activities in your region could affect other parts of the globe?

Step 8. Distribute the *Global Pathways of Wind and Water Work Sheet*, **and ask students to complete it, either in class or as homework.**

Student Assessment

The *Global Pathways of Wind and Water Work Sheet* can be used for student assessment. An assessment rubric is provided.

Further Investigations

- **Visit from a Meteorologist**. Ask a meteorologist to speak to the class about regional and global patterns of air and water circulation.
- **Input/Output.** Have students choose one input or output to learn more about, such as volcanic dust, seeds, or insects. They can look into the distribution and/or source of the input or output item they choose, and if it's an animal or plant, they can study its life cycle and its patterns of movement.
- **Your Region's Winds.** Suggest that students discover more details about the circulation of winds in their region. Have them identify the sources of the winds in their region during different times of the year, and draw a map of the region showing wind circulation during the winter months.
- **Connections.** Ask students to pick another region that their Earth system region is connected to, either by a shared boundary or by wind and water currents. Find a GLOBE school there. Monitor that school's GLOBE data for a few weeks, and compare your GLOBE measurement to theirs. How are they the same? Why? How are they different? Why?.
- **Find Your Watershed Address.** (For classes that are familiar with watersheds and have identified a watershed as a region for Earth system study):

  Using maps, the class considers where their study site watershed fits within the larger scale of watersheds – regionally, within their continent, and globally. They then find their "watershed address."

  Distribute copies of the Hydrology study site watershed map to students. Post the other maps where the class can see them. Have students identify the watershed into which their watershed stream flows by following its course on the map. Name that larger watershed by the name of its largest stream or river. Then ask students to identify the watershed into which that larger watershed stream or river flows, and continue until they have reached the largest possible watershed.

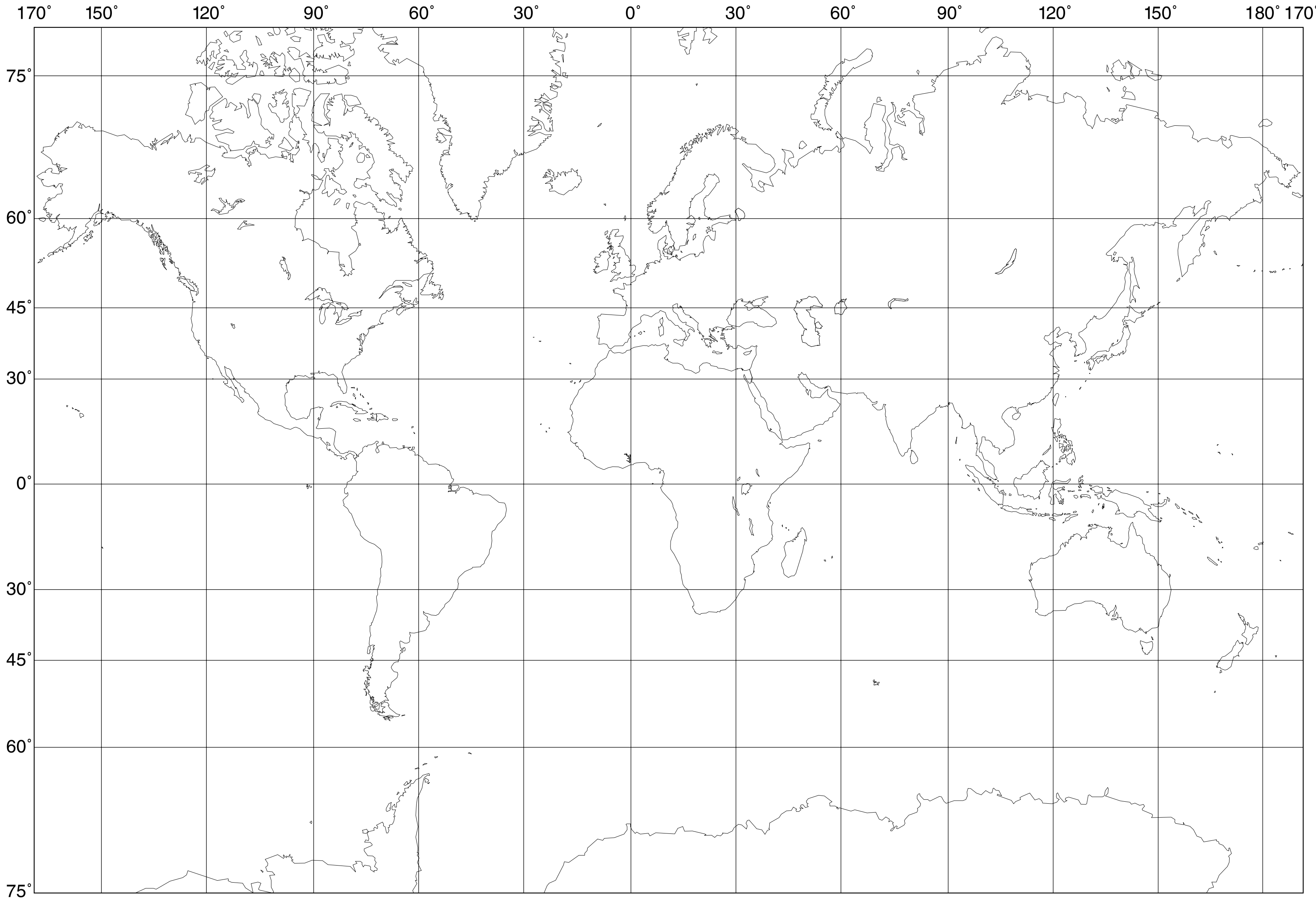
As each larger watershed is identified, have a student volunteer to write the watershed names on the board, drawing arrows from the smaller watershed names to the larger ones. The rest of the students can do this at their desks. When students write those names in the order of the largest watershed to the smallest, they will have their "watershed address."

Sample watershed address:
Atlantic Ocean > Chesapeake Bay > Patuxent River > Western Branch > Folly Branch

Figure EA-GC1-1: Tracing Water Currents and Winds: Black Outline Map of World

Work Sheet-1

Name:______________________________Class: ____________________Date:__________



Global Pathways of Wind and Water

Work Sheet-2

Name:________________________________ Class: ______________________Date:___________

You have traced pathways of wind and water currents to and from your region.

1. Wind

a. What are the regions from which wind blows <u>into</u> your region? Write down real geographic names (for example, write the name of a mountain chain, not just “mountains”).

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b. What might the wind be bringing <u>into</u> your region? Think about the places the wind is coming from, what happens there, what lives there. Think about dust, insects, tiny seeds, smoke, air masses of cooler or warmer temperatures, and moisture. Be specific in your responses.

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c. When wind blows <u>out of</u> your region, what region does it blow into? Again, write down real geographic names.

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d. What might the wind be carrying <u>out of</u> your region? Is it the same as what it brought in? Be as specific as you can about what is being carried, and where it goes.

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2. Water

a. What are the regions from which water flows <u>into</u> your region? Write down geographic names.

b. What might the water be bringing into your region? Be as specific as you can.

c.When water flows <u>out of</u> your region, what regions does it flow into? Again, write down geographic names.

d. What might the water be carrying <u>out of</u> your region? Be specific.

3. Pathways That Matter

What events and activities in other parts of the globe could affect your region? Describe events and activities that are caused by people (such as making dams) and those caused by nature (such as volcanic eruptions).

What events and activities in your region could affect others parts of the globe?

4. Open System / Closed System

Earlier in this activity, you identified inputs (what comes in) and outputs (what goes out) for your region as a system. The output of one system can be the input of another system.

Open systems have lots of inputs and outputs, and closed systems do not. Would you say that your region is an open system, or a closed one? Why?

Figure EA-GC1-2: World Map of Average Ocean Currents. Solid lines are warm currents and dashed lines are cold currents.

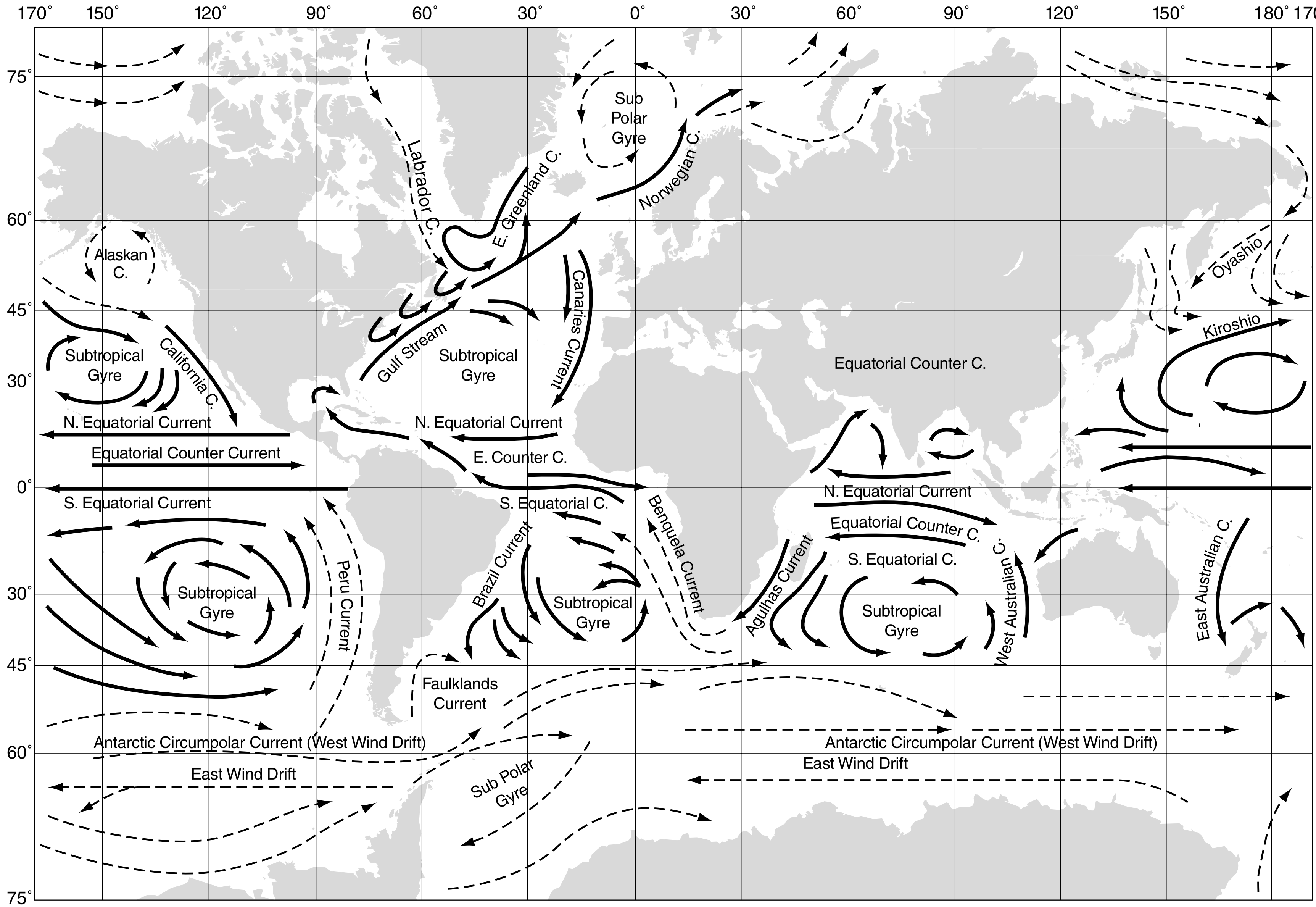

Figure EA-GC1-3a: World Maps of Average Winds in January

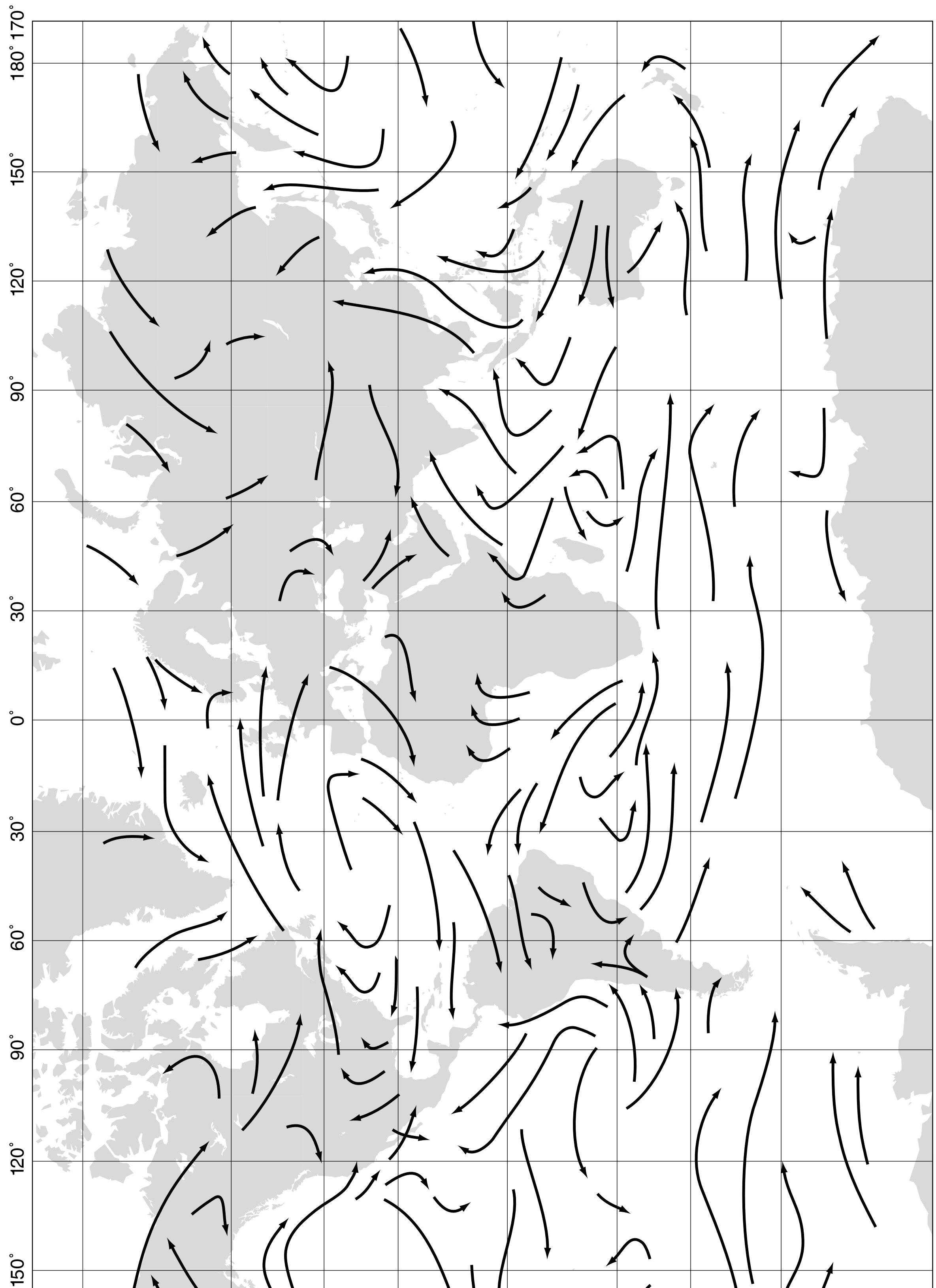

Figure EA-GC1-3b: World Maps of Average Winds in July

Assessment Rubric: GC1: *Your Regional to Global Connection*

Tracing Water Currents and Winds from this Region to Others

	4	3	2	1
Water Pathways accurately	Marks pathways very clearly, completely, and	Marks some pathways clearly and accurately	Marks few pathways clearly and accurately them inaccurately	Has not yet marked pathways, or has marked
Geographic Place Names for Water Pathways	Lists all place names completely and accurately	Lists most place names accurately	Lists some place names accurately	Has not yet listed any place names accurately
Wind Pathways	Marks pathways very clearly, completely, and accurately	Marks some pathways clearly and accurately	Marks few pathways clearly and accurately.	Has not yet marked pathways, or has marked them inaccurately
Geographic Place Names for Wind Pathways	Lists all place names completely and accurately	Lists most place names accurately	Lists some place names accurately	Has not yet listed any place names accurately

Assessment Rubric: GC1: *Your Regional to Global Connection*

Global Pathways to Wind and Water

	4	3	2	1
Wind Connections which wind blows	Accurately names regions from which and to to which wind blows	Accurately names some regions from which and and to which wind blows.	Accurately names 1 or 2 regions from which or to which wind blows	Does not accurately name regions from which
Water Connections	Accurately names regions from which and to which water flows	Accurately names some regions from which and to which water flows	Accurately names 1 or 2 regions from which and to which water flows	Does not accurately name regions from which or to which water flows
Activities That Affect Connected Regions	Thoughtfully and accurately describes several human activities, and events not caused by humans, that affect own region and others. Reflects understanding that regions are interconnected	Accurately describes a few human activities, and events not caused by humans, that affect own region and others. Reflects understanding that regions are interconnected	Describes 1 or 2 human events, and. events not caused by humans, that affect own region and others Reflects minimal understanding that regions are interconnected.	Describes no human activities or events not caused by humans that affect own region or others. Reflects no understanding that regions are interconnected
Region as Open System	Identifies region as an open system, and explains that a lot of substances and living things cross its boundaries	Identifies region as an open system, yet gives unclear explanation why	Identifies region as an open system, yet does not explain why	Does not respond to question, or identifies region as a closed system

GC2: Components of the Earth System Working Together

Purpose

To develop familiarity with interactions among the major components of the Earth system at the global scale

Overview

Students review a variety of images and maps of the whole Earth in order to identify the major components of the Earth system at the global scale. The maps show solar energy, average temperature, cloud cover, precipitation, soil moisture, and vegetation, and the images are of the Earth from space. As a class, they discuss some ways that the components of the Earth system interact to form the whole Earth system. They describe the water cycle at the global scale in greater detail, identify the components through which water passes and the processes that move it, and draw an abstract diagram.

Student Outcomes

Students will be able to:

- Use images and data about the whole Earth to identify the major components of the Earth system at the global scale and stimulate their thinking about connections among those components;
- Describe the pathway of water among the components, as an example of ways they are connected;
- Translate their understanding of that pathway into an abstract diagram.

Science Concepts

Physical Sciences

Heat is transferred by conduction, convection and radiation.

Heat moves from warmer to colder objects.

Sun is a major source of energy for changes on the Earth's surface.

Energy is conserved.

Chemical reactions take place in every part of the environment.

Earth and Space Sciences

Weather changes from day to day and over the seasons.

The sun is the major source of energy at Earth's surface.

Solar insolation drives atmospheric and ocean circulation

Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere).

Life Sciences

Organisms can only survive in environments where their needs are met.

Earth has many different environments that support different combinations of organisms.

Organisms' functions relate to their environment.

Organisms change the environment in which they live.

Humans can change natural environments.

Plants and animals have life cycles.

Ecosystems demonstrate the complementary nature of structure and function.

All organisms must be able to obtain and use resources while living in a constantly changing environment.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Populations of organisms can be categorized by the function they serve in the ecosystem.

Welcome Introduction Protocols Learning Activities Appendix

Sunlight is the major source of energy for ecosystems.

The number of animals, plants and microorganisms an ecosystem can support depends on the available resources.

Atoms and molecules cycle among the living and non-living components of the ecosystem.

Scientific Inquiry Abilities

Analyzing and images of the Earth from space

Analyzing global datasets displayed on maps

Develop explanations and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate results and explanations.

Time

One class period

Level

Middle, Secondary

Materials and Tools

3 satellite images of the Earth (Figure EA-GC2-1) provided in *Teacher's Guide*

6 maps showing the whole Earth in the month of January (Figure EA-GC2-2) provided in *Teacher's Guide*

2-3 sheets of paper for each student, for drawing diagrams

Sample beginning student diagram (provided by GLOBE) – Sample complete student diagram (not to be distributed to students)

Preparation

Make student copies

Prerequisites

Students must:

- Be able to obtain information from a map on which different colors represent different values;
- Have learned the general path of water through the water cycle.

Crosswalks to Other GLOBE Learning Activities

An Activity Guide accompanies the GLOBE Earth System Poster *Exploring the Connections in a Typical Year.* The Guide describes how to help students explore patterns in the data displayed on the poster. Students find annual changes, relationships among types of data, and global patterns, and they make connections with GLOBE data.

What to Do and How to Do It

Step 1. Preparation

Make Student Copies

- 6 maps showing the whole Earth in the month of January, from the GLOBE Earth System Poster, *Exploring the Connections in a Typical Year.* The 6 maps are:
  - Solar Energy
  - Average Temperature
  - Cloud Cover
  - Precipitation
  - Soil Moisture
  - Vegetation
- 3 satellite images of the Earth (Figure EA-GC2-1) showing:
  - North and South America
  - Africa and Europe
  - Japan and Australia
- *Water at the Global Scale Work Sheet*
- Sample beginning student diagram
- Assessment rubric for this activity (You may want to share with students.)
- *Student Self-reflection Log: The Earth System at the Global Scale*

Step 2. Have the class review and discuss the satellite images of the Earth and the maps of different aspects of the Earth.

Explain to students that a new discipline of science has emerged – Earth System Science in which people are learning about ways that *parts* of the Earth *interact* to make the whole Earth system. Data gathered by instruments on satellites orbiting the Earth are fundamental to this approach. These data, together with information obtained at the surface, can be put into the form of maps that cover the whole globe.

Distribute student copies of the images and maps, and give students some time to look them over.

Ask students to describe for the class what they see in the images and maps. Do they understand what these are showing? Go over the captions with them to clarify what they may not understand.

Tell them that they are not expected to understand absolutely everything about these images and maps. They should study them carefully and share with the class what they see, based on the captions and on their previous studies and experience.

Step 3. Ask students to identify the major parts, or components, of the Earth system that appear to be involved in each of the images and maps.

Have students look at the images and maps one by one, and name all the major components of the Earth system that they see represented.

Students may suggest such components as:

- oceans
- land
- clouds
- air
- rain
- soil
- plants
- animals
- rocks
- people
- ice (at the poles)

Then make sure that they synthesize all the components they've suggested into a small number of major components.

For the purpose of these Earth system science learning activities, GLOBE has identified four major components:

1. Air, including precipitation and clouds (atmosphere);
2. Water: bodies of water such as canals, streams, ponds, lakes, oceans, and groundwater (hydrosphere);
3. Soil (pedosphere);
4. Living things (biosphere).

It is all right if students choose a slightly different set of major components. They may include ice and snow (cryosphere), or rocks (lithosphere).

Step 4. Have students begin to identify connections among these global Earth system components, then focus on the global water cycle. Students will develop diagrams of the global water cycle.

Ask students for their ideas about some ways these major components are connected at the global scale. Discuss their ideas as a class.

Now focus on the water cycle and the pathway that water takes as it moves among the components. Distribute the *Water at the Global Scale Work Sheet-1* . Give students 20-30 minutes to complete the work sheet.

In Question 4 of the *Work Sheet*, students may need to see a copy of the sample beginning student diagram (Figure EA-GC1-1) to understand what is required.

Step 5. Have student volunteers share their water drop pathway descriptions and diagrams with the class.

Have the students identify the components and the processes involved in each major step of the pathway.

You may wish to add aspects of the water cycle that students may not have covered on their own. The example of a complete diagram is provided for this purpose. See Figure EA-GC2-3.

Point out to students that if a diagram of just one aspect of the Earth system, water, is complicated, they can imagine how very complicated it is to look at all aspects of the system together. That is just what scientists do when they create a computer program to simulate the Earth system and how it changes over time. This computer program is called a model. The more that is included in a model, the better it simulates the real Earth system *but* the harder it is for scientists to determine how things change. However, even the most complex computer model is much simpler than the real Earth system!

Step 6. Collect the *Work Sheets* **for assessment.**

Student Assessment

Two *Work Sheets* can be used for assessment:

Water at the Global Scale

Student Self-reflection Log: The Earth System at the Global Scale

An assessment rubric for the first work sheet is provided. Students' responses to the questions on the *Self-reflection Log* cannot be quantified, yet they play a special role in student learning. Students may be willing to describe confusion they feel or other problems they're having that they would not feel free to bring up with the whole class.

Water at the Global Scale

Work Sheet-1

Name:________________________________Class: ______________________Date:___________

The images of the Earth from space and world maps that your teacher has given you are some of the ones that Earth system scientists use in their efforts to understand the Earth as a whole. The images have been made by different kinds of instruments, some on different satellites that orbit the Earth, and some on the ground. GLOBE students make some of these kinds of measurements, as you probably know!

The Earth is extremely complicated. Looking at it as parts that interact to form the whole can help you think about it more clearly.

1. Major Components.

As you study these images, what major parts, or components, of the Earth system do you find represented? List them here.

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2. The Pathway of a Drop of Water.

Using the list of components of the Earth system that you made for Question 1, think about the pathways that water takes through the system. Tell the story of a drop of water, and describe what happens to it. Through which components does it travel, and how does it get there?

Describe the water drop's path as a series of steps. For example:

Step 1. It rains, and the water drop falls near my house.

Step 2. The water is absorbed by the soil.

You can add any details that you imagine. Remember to include the various forms that water takes (solid, liquid, and gas).

Turn your water drop into a world traveler, and take it across the globe. Don't leave it in your neighborhood!

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3. Water Connects Components.

Now go back through your steps. After each one, write the name of the system components that were involved.

For example, if you wrote, "It rains, and the water drop falls near my house," after that, you would write, "atmosphere."

If you wrote, "The water is absorbed by the soil," after that, you would write, "Soil," or "Pedosphere" (another word for soil).

4. Diagram the Water Cycle.

Get a clean sheet of paper. Write the names of the major Earth system components that you listed in Question 1, far apart from each other on the page. (It doesn't matter in what order you write them.) Draw a circle around each name.

For each step in the water pathway during which water moved from one major Earth system component to another, draw an arrow between the two components. For example, if you described water being evaporated from the ocean, draw an arrow from the ocean to the atmosphere.

Along the shaft of each arrow, write a short phrase describing how the water moved from one component to the other. For example, on the shaft of the arrow from the ocean to the atmosphere, you would write, "Water evaporates from the ocean."

Do this for all your water pathway steps that involve water moving from one system component to the other.

Your teacher will show you a copy of a sample diagram. It will give you an idea of how to begin.

The Earth System at the Global Scale

Work Sheet-2: Student Self-reflection Log

Name:______________________________Class: _____________________Date:__________

Your responses to the questions below are intended to help your teacher become aware of what you're thinking and what you may need help understanding. <u>You will not be graded on these responses</u>.

1. How useful did you feel the global maps and satellite images were in helping you identify Earth system components? Why? Please explain.

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2. What, if anything, did you find confusing or difficult about looking at Earth system components at the global scale?

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3. How would you describe the Earth system at the global scale?

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EA-GC2-1a: 3 satellite images of the Earth in January (from 3 different satellites) showing: a) North and South America, b) Africa and Europe, c) Japan

a) North and South America

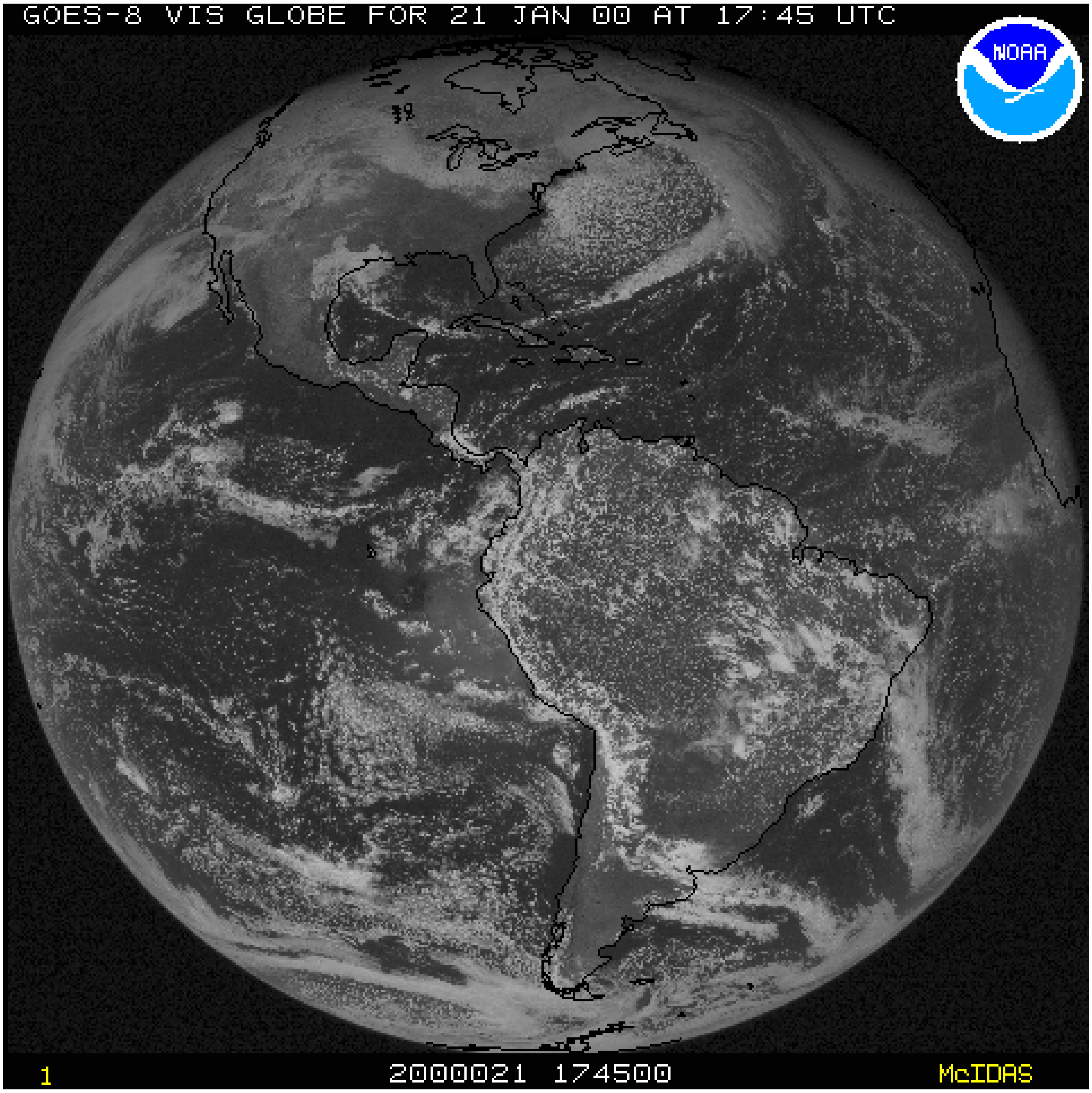


Figure EA-GC2-1b: Africa and Europe

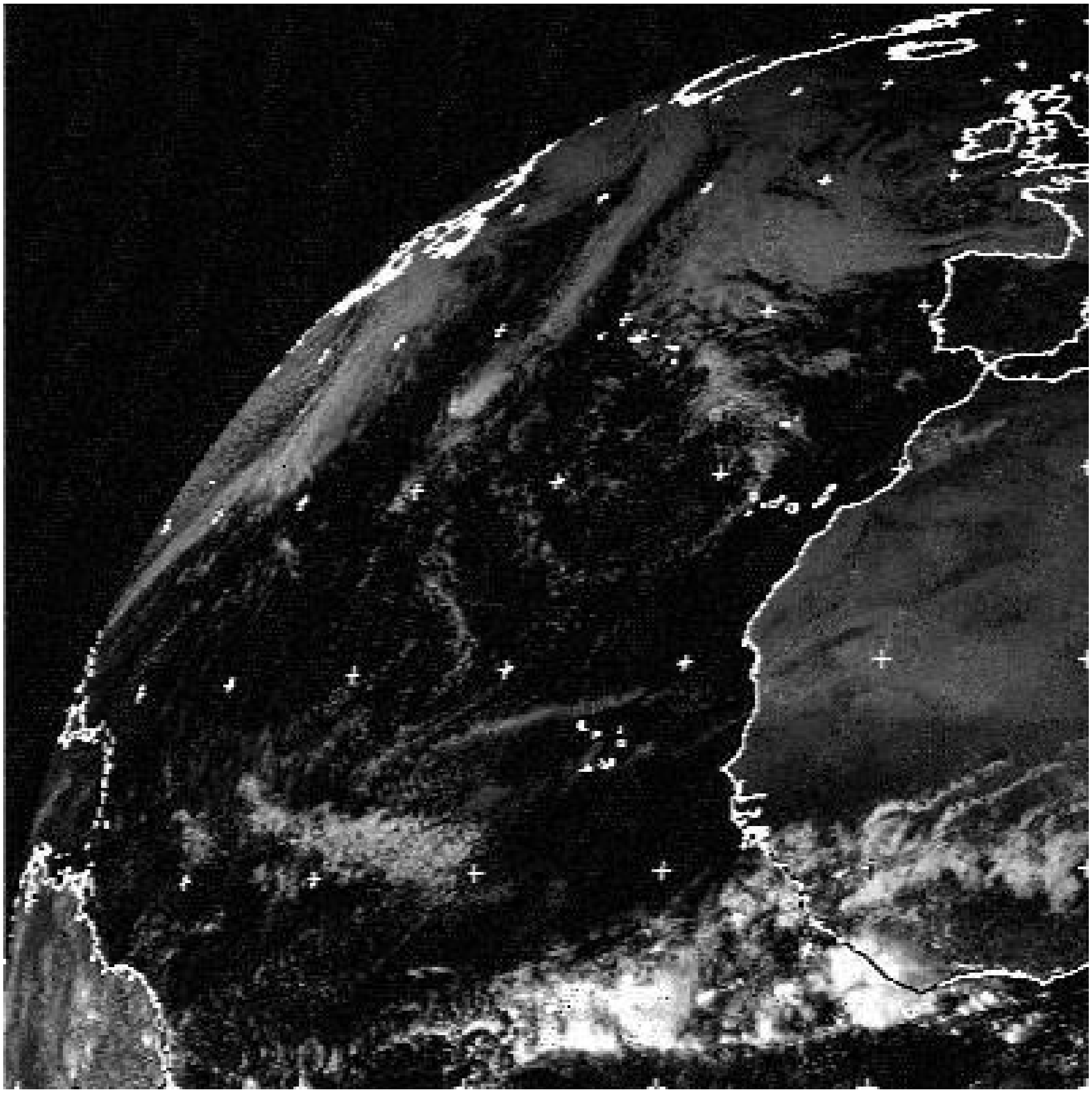
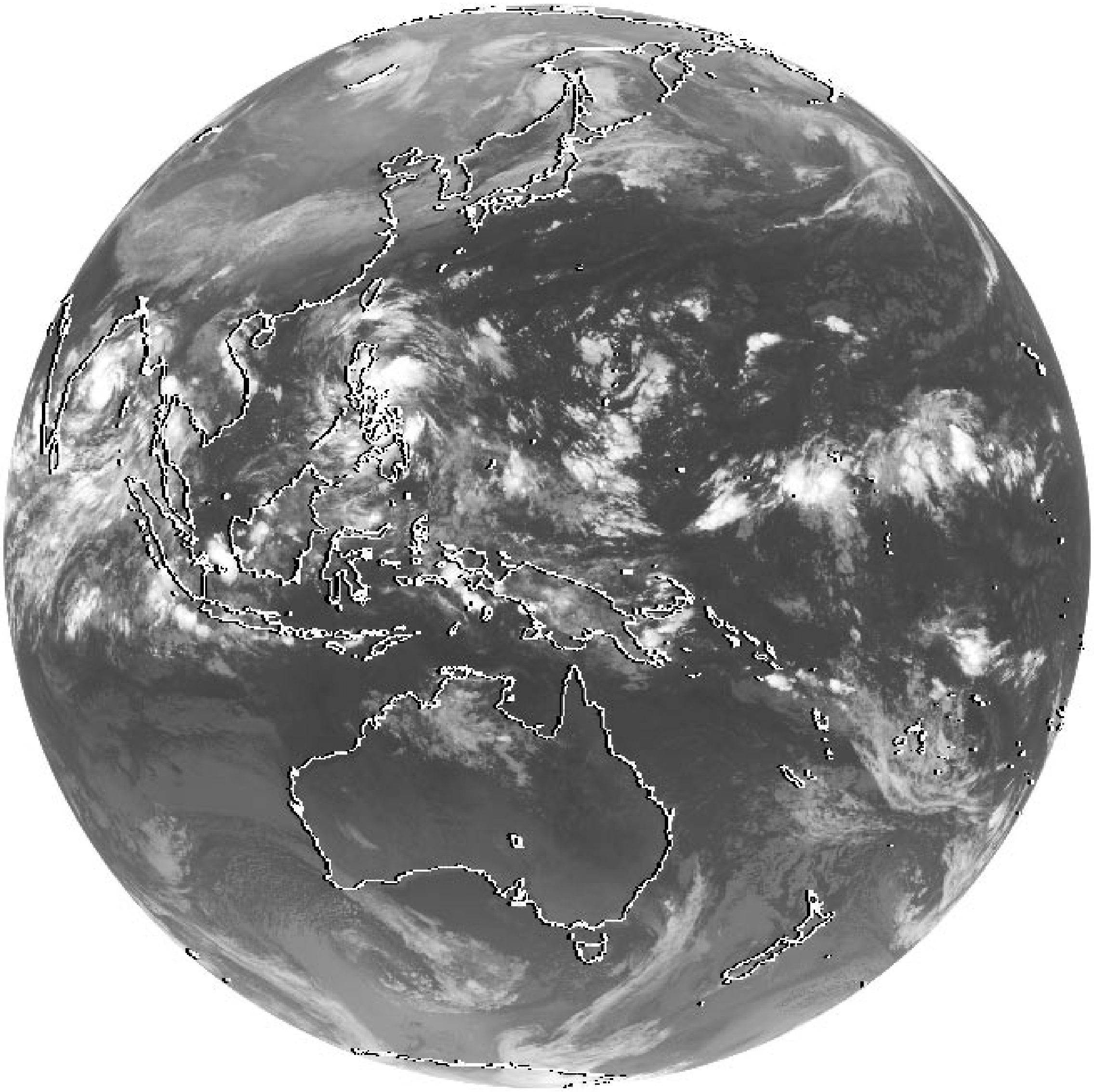
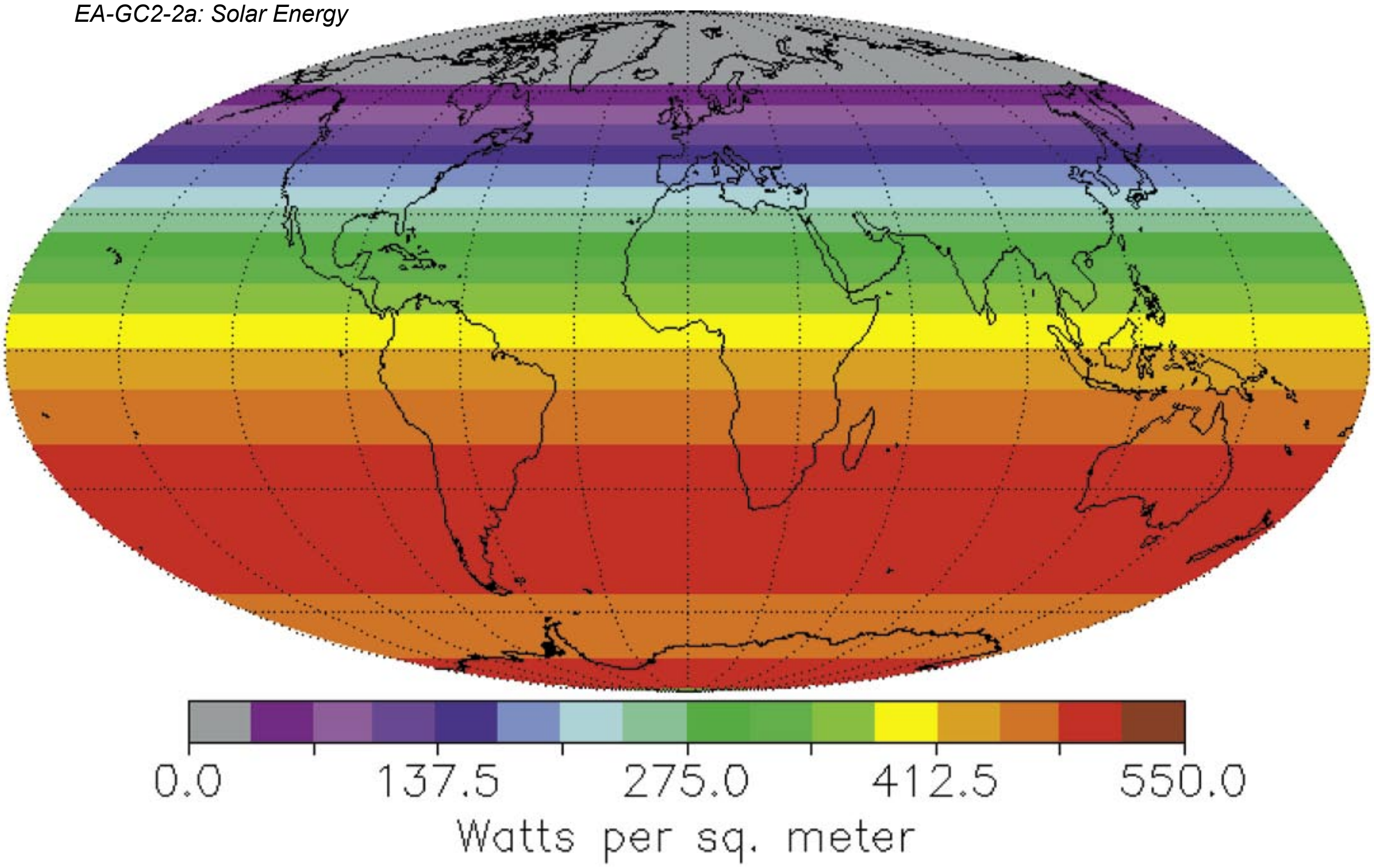


Figure EA-GC2-1c: Japan and Australia

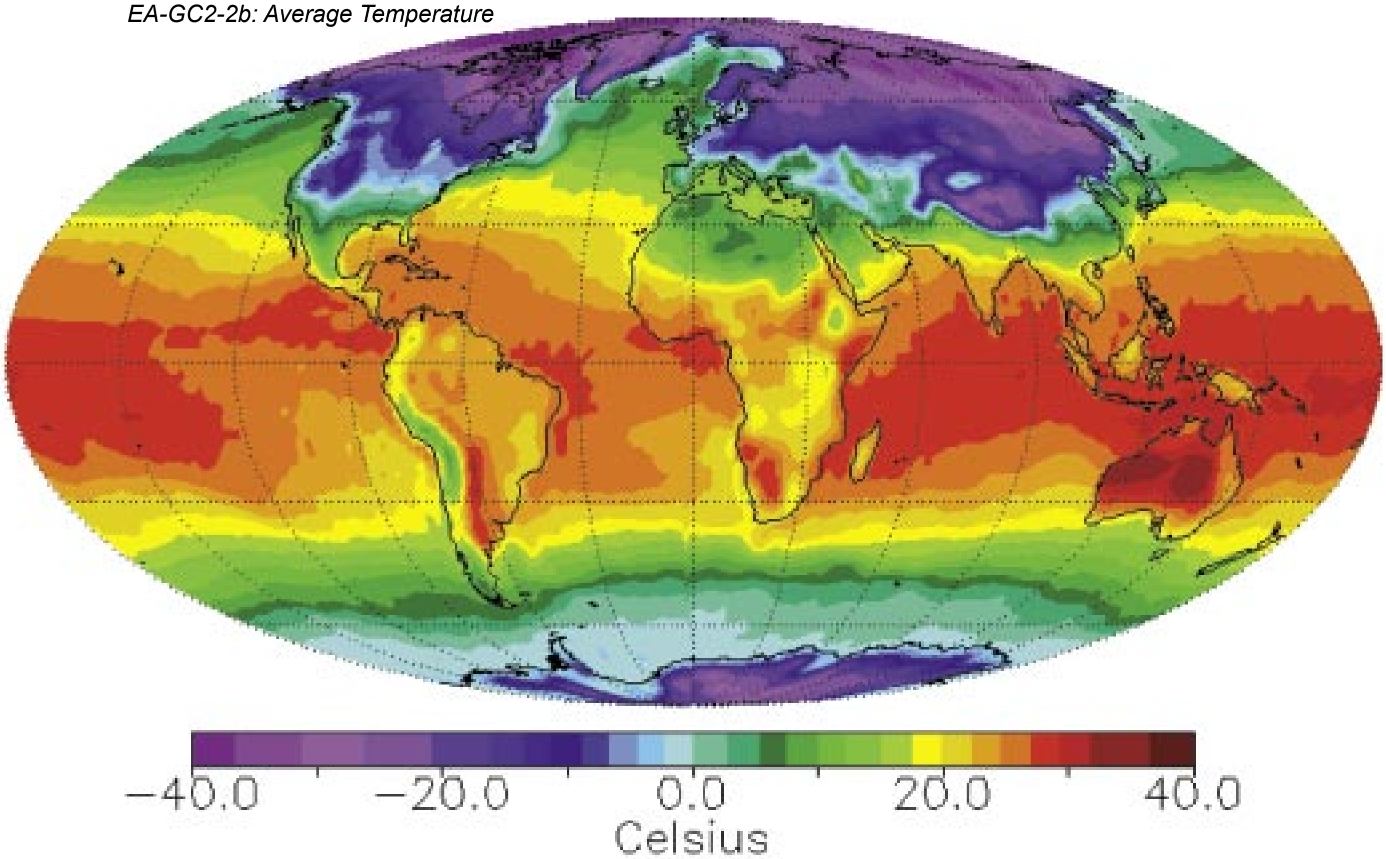


EA-GC2-2a-f: 6 maps showing the whole Earth in the month of January from the GLOBE Earth System Poster, Exploring the Connections in a Typical Year, showing a) Solar Energy, b) Average Temperature, c) Cloud Cover, d) Precipitation, e) Soil Moisture, f) Vegetation

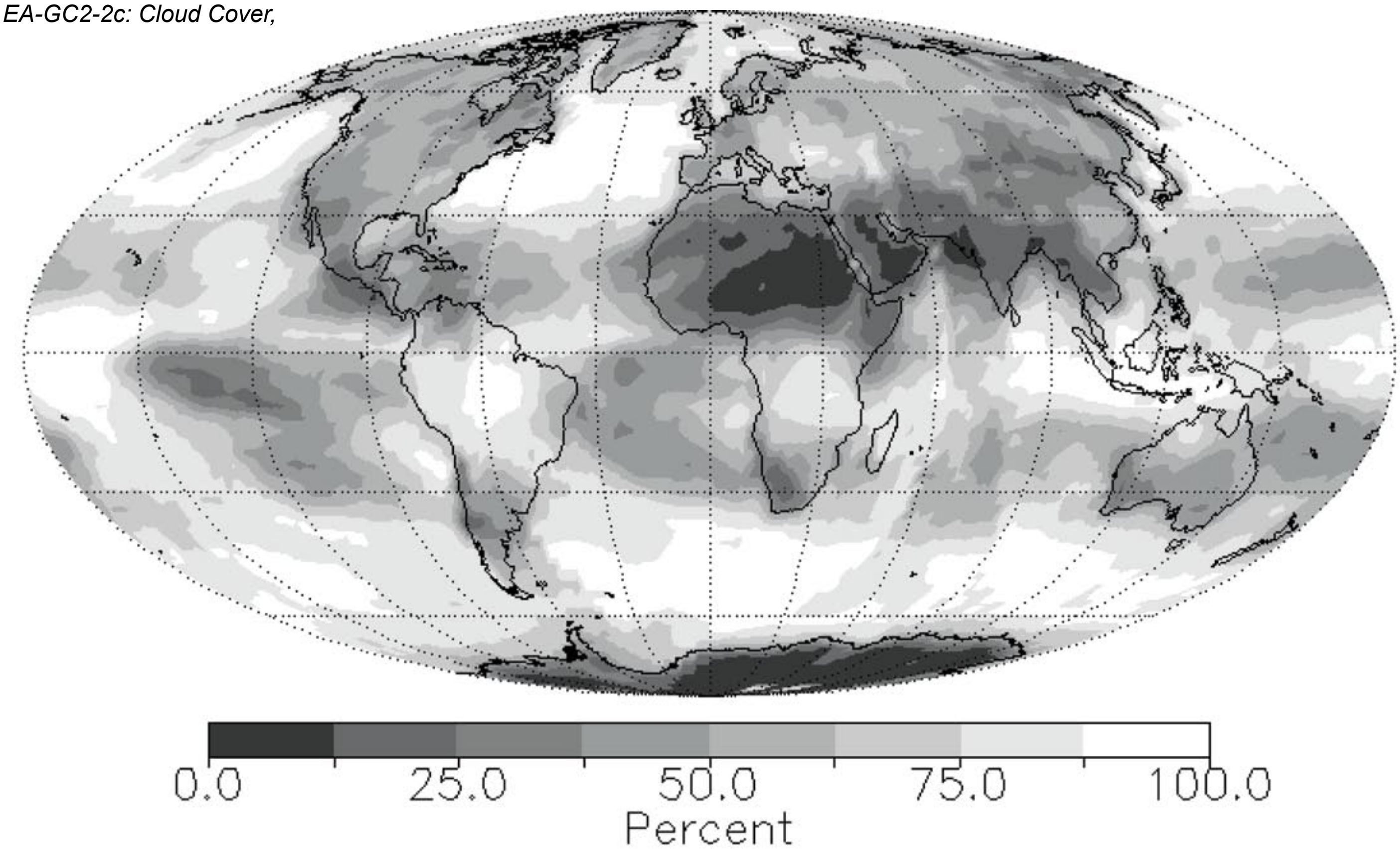
EA-GC2-2a: Solar Energy



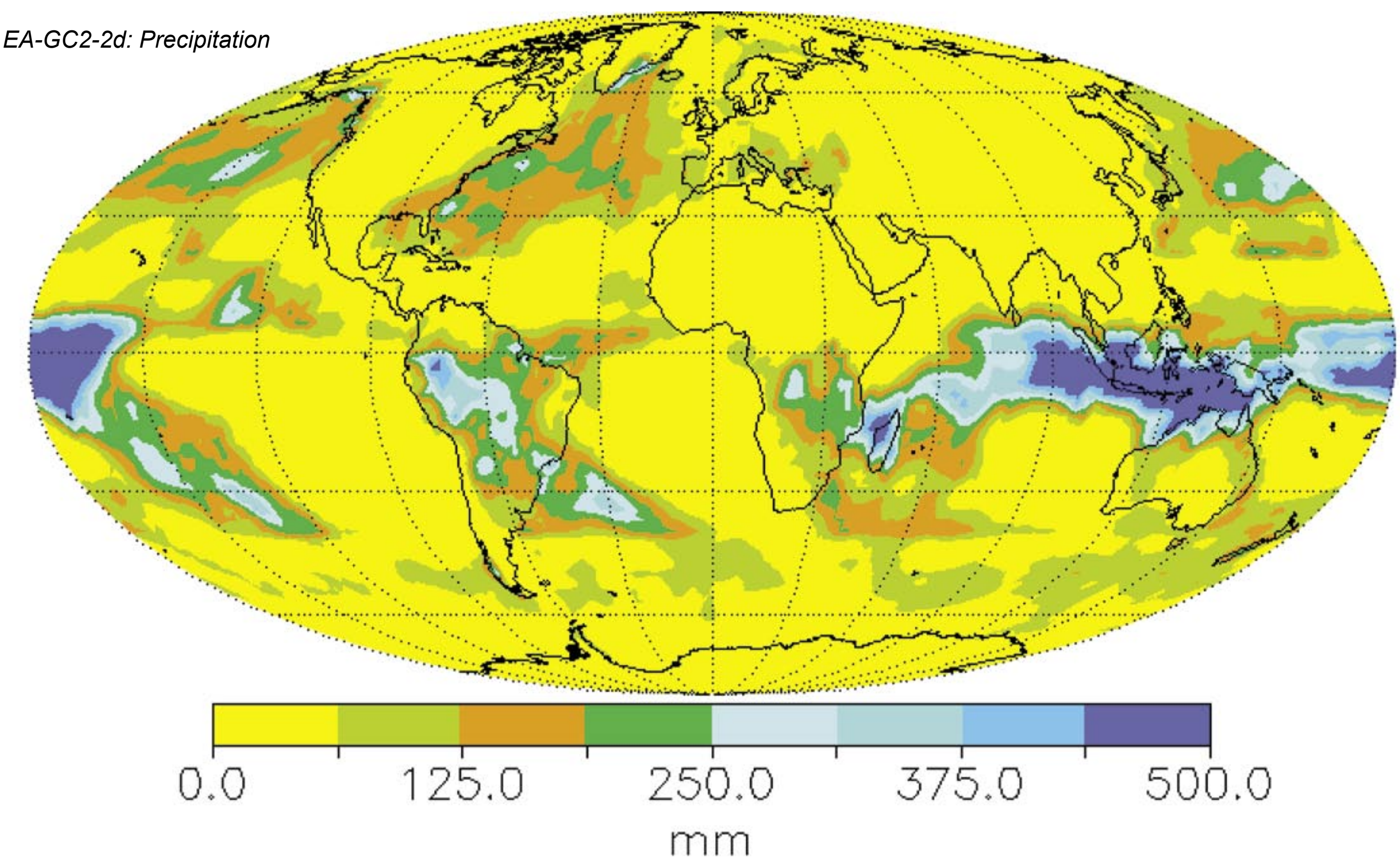
EA-GC2-2b: Average Temperature



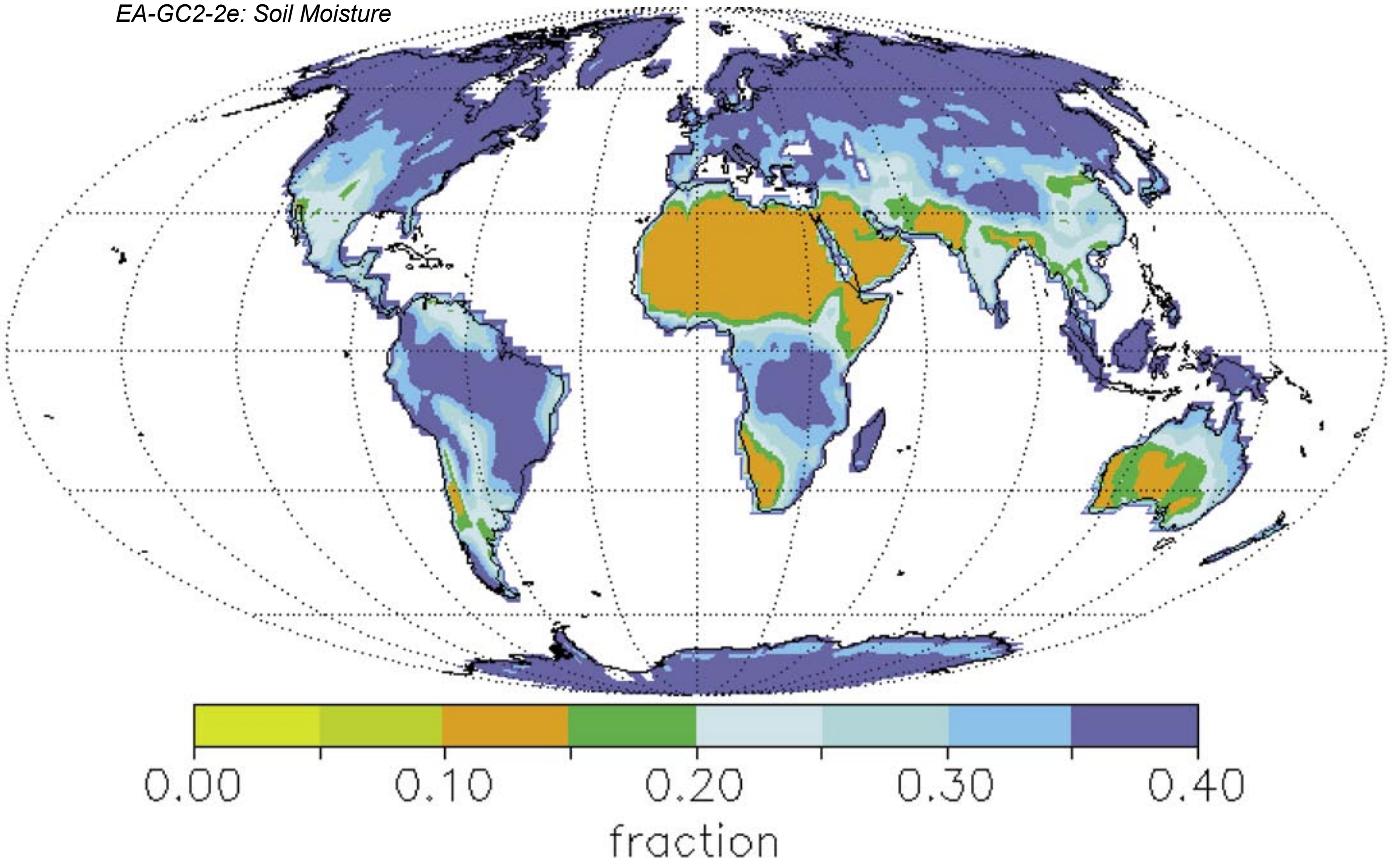
EA-GC2-2c: Cloud Cover,



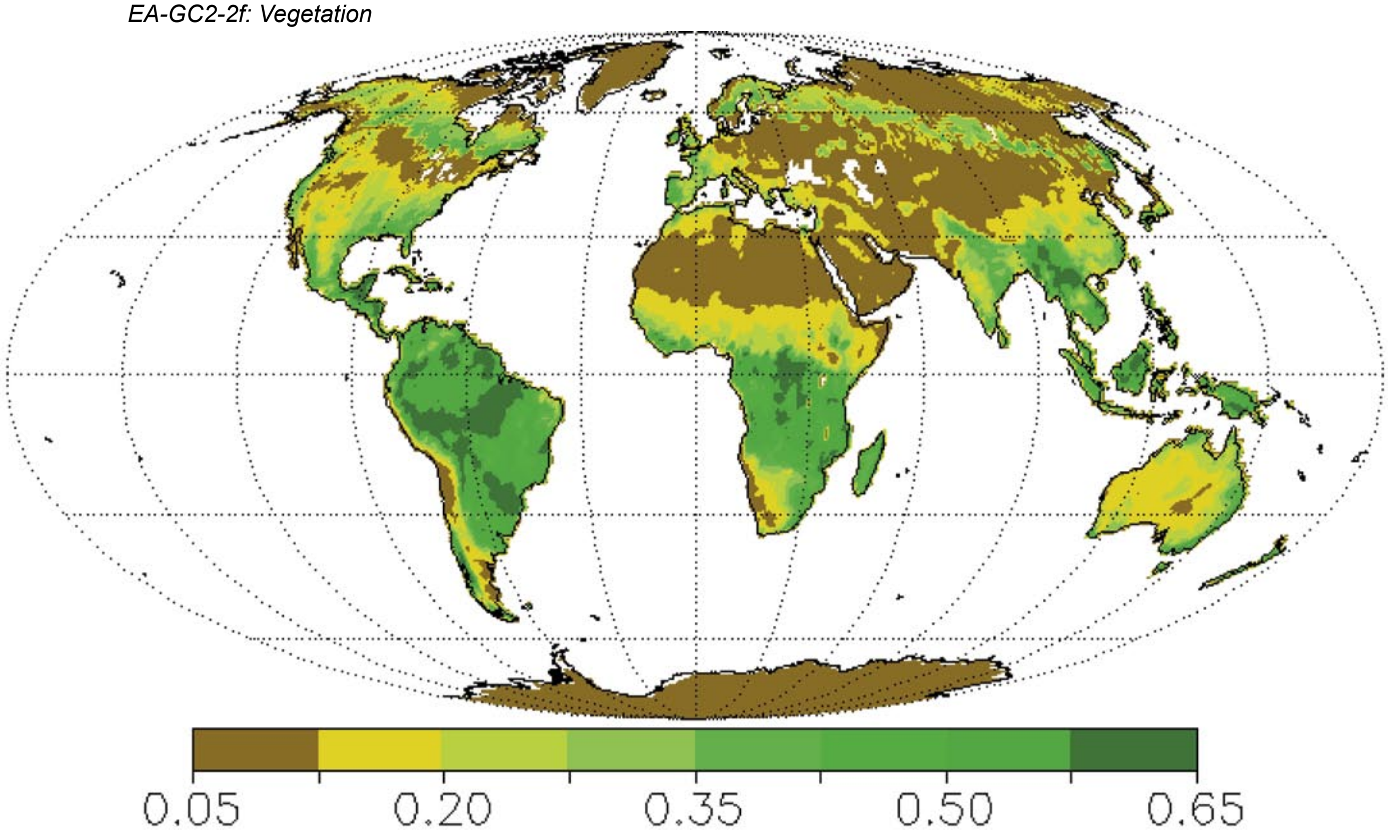
EA-GC2-2d: Precipitation



EA-GC2-2e: Soil Moisture



EA-GC2-2f: Vegetation



Assessment Rubric: GC1: *Water at the Global Scale*

Water at the Global Scale

	4	3	2	1
List of System Components or completely list components **Images**	Completely and accurately lists all major **Represented in Global**	Completely and accurately lists most major components	Partially lists major components components	Makes little attempt to accurately and to which wind blows.
Description of Water Pathway Through Components at Global	Fully describes pathway of water through components, accurately and with elaborate detail	Adequately and accurately describes pathway of water through components	Partially describes pathway of water through components	Describes very little of pathway of water through components.
List of System Components Associated with Steps along Water Pathway	Accurately lists all components associated with each step along pathway.	Accurately lists most components associated with each step along pathway	Partially lists components associated with each step along pathway	Lists few components associated with pathway
Diagram of Water at the Global Scale	Completely and clearly represents interconnections that water makes among components at the global scale, and demonstrates all expected science knowledge	Completely and clearly represents most interconnections that water makes among components, and demonstrates most expected science knowledge	Somewhat clearly represents a few inter-connections that water makes among components, and demonstrates some expected science knowledge	Inadequately develops interconnections among components of site, and demonstrates little expected science knowledge

Figure EA-GC2-3: Sample Beginning Student Diagram for Journey of a Water Drop

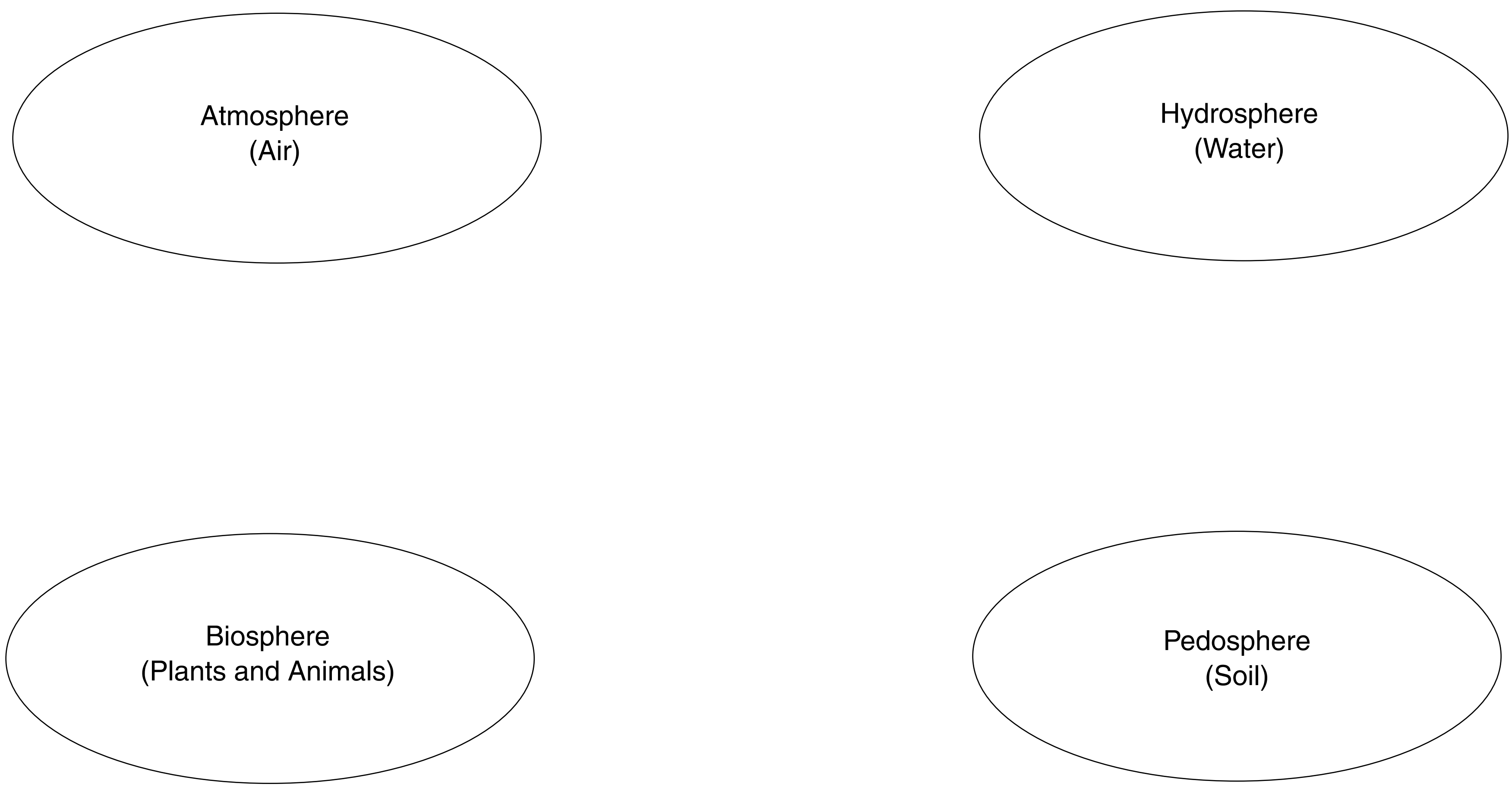
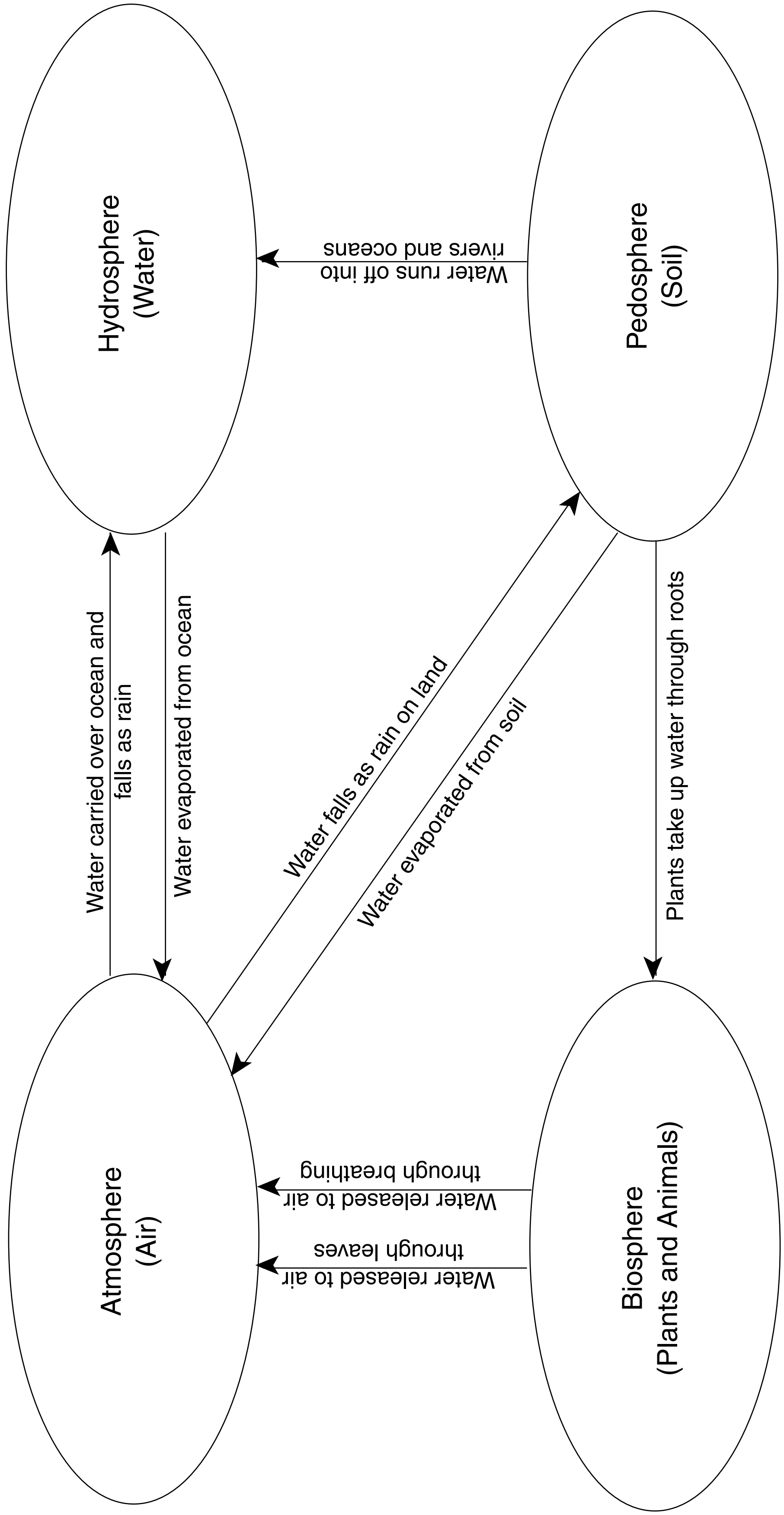
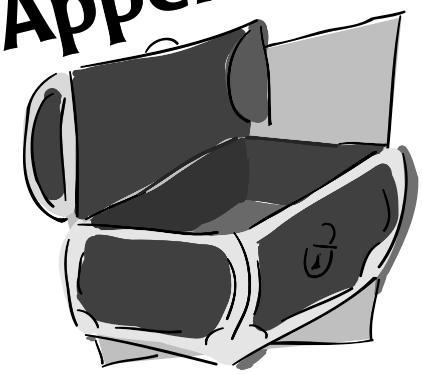


Figure EA-GC2-4: Sample Completed Student Diagram for Journey of a Water Drop



Appendix



Earth System Science Investigation

Budburst Site Definition Sheet

School Name: ______________________________Class or Group Name:______________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: __________________________

Site name (give your site a unique name):____

Coordinates: Latitude: ____________________ ❒ N or ❒ S (check one)
Longitude: ____________________ ❒ E or ❒ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❒ GPS ❒ Other

If other, describe:____

Tree or shrub Label	Genus	Species

Comments (metadata):

1. Are the trees or shrubs in the understory?
2. At this site, are there more than one dominant species?

Other comments: ____

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Earth System Science Investigation

Green-Up and Green-Down Site Definition Sheet

School Name: ____

Observer Names: ____

____

Date: ____________________ Check one: ❒ New Site ❒ Metadata Update

Study Site name (give your site a unique name):______________________________

Coordinates: Latitude: ________________ ❒ N or ❒ S (check one)
Longitude: ________________ ❒ E or ❒ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❒ GPS ❒ Other

If other, describe:____

Nearest Atmosphere Site: ATM-______

Distance to Site: ____ meters; Direction to Site: ❒ N ❒ NE ❒ E ❒ SE ❒ S ❒ SW ❒ W ❒ NW

Type of site: ❒ Atmosphere Study Site ❒ Land Cover Sample Site ❒ Other

If other, describe: ____

____

For each tree, shrub or grass plot, provide the following information.
Species is NOT required for grasses.

Tree, Shrub, or Grass Label	
Genus	
Species	
Common Name	

Comments:

____

____

____

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____

____

Budburst Protocol
Data Sheet

School Name: ______________________________ Class or Group Name: ______________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: ________________________

Site name (give your site a unique name): ____

	Tree Label: ____________		Tree Label: ____________	
Date	Are tiny leaves emerging? Yes or No	Can budburst be seen on 3 locations on the tree? Yes or No	Are tiny leaves emerging? Yes or No	Can budburst be seen on 3 locations on the tree? Yes or No

Comments: ____

____

____

____

Earth System Science

Tree and Shrub Green-Up Data Sheet

School Name: ______________________________ Study Site: PHN-______________

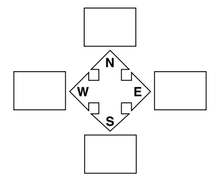
Observer Names:____

Plant Scientific Name: Genus_____________________ Species: ___________________

Plant Common Name: ____

Green-Up Cycle:_____________ Year:__________

Photo Number and Orientation



Tree and Shrub Green-Up

Date (day and month)	**Leaf 1** (dormant, swelling, budburst, length (mm), lost)	**Leaf 2** (dormant, swelling, budburst, length (mm), lost)	**Leaf 3** (dormant, swelling, budburst, length (mm), lost)	**Leaf 4** (dormant, swelling, budburst, length (mm), lost)	**Reported to GLOBE**
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑

Check the last column on the green-up table when you report your data to GLOBE.

Comments *(date each comment):*

____

____

Earth System Science

Grass Green-Up Data Sheet

School Name: ______________________ Study Site: PHN-__________

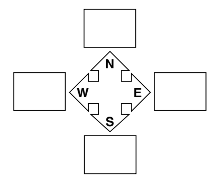
Observer Names:____

Plant Scientific Name: Genus________________________________

Plant Common Name: ______________________________________

Green-Up Cycle:__________ Year:________

Photo Number and Orientation



Grass Green-Up

Date (day and month)	**Leaf 1** (No shoot length (mm), or lost)	**Leaf 2** (No shoot length (mm), or lost)	**Leaf 3** (No shoot length (mm), or lost)	**Leaf 4** (No shoot length (mm), or lost)	**Reported to GLOBE**
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑

Check the last column on the green-up table when you report your observations to GLOBE.

Comments *(date each comment):*

____

____

____

Earth System Science

Tree, Shrub, and Grass Green-Down Data Sheet

School Name: ______________________________ Study Site: PHN-______________

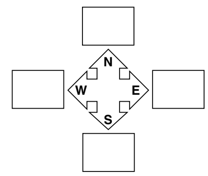
Observer Names:____

Plant Scientific Name: Genus____________________ Species: ___________________

Plant Common Name: ____

Green-Down Cycle:______________ Year:__________

Photo Number and Orientation



Tree, Shrub, and Grass Green-Down

Date (day and month)	**Leaf 1** (Color, fallen, snow covered)	**Leaf 2** (Color, fallen, snow covered)	**Leaf 3** (Color, fallen, snow covered)	**Leaf 4** (Color, fallen, snow covered)	**Reported to GLOBE**
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑
					❑

Check the last column on the green-up table when you report your observations to GLOBE.

Comments *(date each comment):*

____

____

____

Ruby-throated Hummingbird (RTHU)

Site Definition Data Sheet

School Name: ________________________ Class or Group Name:___________________________

Name(s) of student(s) filling in *Data Sheet:*____

____

Date:_____________________

Site Name (give your site a unique name):____

Coordinates: Latitude:_________ ❑ N or ❑ S   Longitude:________ ❑ E or ❑ W

Elevation:____ meters

Source of Location Data (check one): ❑ GPS ❑ Other ___________________________________

Nearest Atmosphere Site: ATM-_________

Distance to ATM Site:________meters;

Direction to Site: ❑ N ❑ NE ❑ E ❑ SE ❑ S ❑ SW ❑ W ❑ NW

Elevation Difference (Soil Moisture Site – Hummingbird Site):_______meters

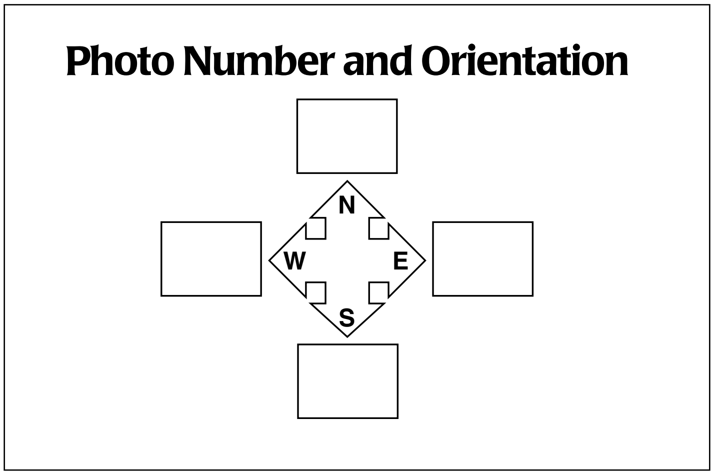
(this value may be positive or negative)

Check If Present At Site: ❑ Hummingbird Feeder ❑ Flowers

If flowers are present, record the following (use additional sheets if needed):

Genus	Species	Common Name

Photo Number and Orientation



Comments (Metadata): ____

Ruby-throated Hummingbird (RTHU)

Hummingbird Sighting Protocol Data Sheet

School Name: ______________________Class or Group Name: _________________________

Name(s) of Student(s) Filling in *Data Sheet:* ____

____

Site Name: ____

	NUMBER OF HUMMINGBIRDS OBSERVED					
Date						
Observation Start Time: (local time)						
Observation End Time: (local time)						
Observation Start Time: (UT)						
Observation End Time: (UT)						
Adult Male *full red throat* February-October (U.S., Canada) January-September ONLY (Mexico, Central America, Caribbean)						
Adult Male (probable adult, but may be an advanced juvenile) *full red throat* October-December (Mexico, Central America, Caribbean)						
Adult Female *white throat* February-April ONLY (U.S., Canada) January-May (Mexico, Central America, Caribbean)						
Undetermined Sex and Age (could be female or young male) *white throat* May-October (U.S., Canada) August-December ONLY (Mexico, Central America, Caribbean)						
Undetermined Sex and Age *throat not observed* Any time of the year (all locations)						
Young Male *throat streaked in green or black and/or one or more red throat feathers* May-October (U.S., Canada) August-April (Mexico, Central America, Caribbean)						

If no hummingbirds are seen, record “0” on the Data Sheet above and enter “0” on the data entry page on the GLOBE Web site.

For any "unusual" RTHU (i.e., one with "abnormal" plumage or one that is color-marked) record in the Data Entry page's Comments section the color of the bird's forehead, crown, throat, breast, belly, flanks, back, tail, bill, and eyes, and the location of other distinct markings. Describe the bird's activity (including feeding behavior). Take a photo if possible. Also follow this procedure for any "vagrant" hummingbirds other than RTHUs from 15 October through 15 March. Please be sure to report any of these "unusual" and "vagrant" hummingbirds directly to research@hiltonpond.org as soon as possible after sighting.

Comments:

Ruby-throated Hummingbird (RTHU)

Feeder Visit Protocol Data Sheet

School Name: ______________________Class or Group Name: __________________________

Name(s) of Student(s) Filling in *Data Sheet:* ______________________________________

____

Site Name: ____

	NUMBER OF FEEDER VISITS					
Date						
Observation Start Time: (local time)						
Observation End Time: (local time)						
Observation Start Time: (UT)						
Observation End Time: (UT)						
Adult Male *full red throat* February-October (U.S., Canada) January-September ONLY (Mexico, Central America, Caribbean)						
Adult Male (probable adult, but may be an advanced juvenile) *full red throat* October-December (Mexico, Central America, Caribbean)						
Adult Female *white throat* February-April ONLY (U.S., Canada) January-May (Mexico, Central America, Caribbean)						
Undetermined Sex and Age (could be female or young male) *white throat* May-October (U.S., Canada) August-December ONLY (Mexico, Central America, Caribbean)						
Undetermined Sex and Age *throat not observed* Any time of the year (all locations)						
Young Male *throat streaked in green or black and/or one or more red throat feathers* May-October (U.S., Canada) August-April (Mexico, Central America, Caribbean)						

Observations are made in 45-minute time blocks. If no hummingbirds are seen, record “0” on the Data Sheet above and enter “0” on the data entry page on the GLOBE Web site.

For any "unusual" RTHU (i.e., one with "abnormal" plumage or one that is color-marked) record in the Data Entry page's Comments section the color of the bird's forehead, crown, throat, breast, belly, flanks, back, tail, bill, and eyes, and the location of other distinct markings. Describe the bird's activity (including feeding behavior). Take a photo if possible. Also follow this procedure for any "vagrant" hummingbirds other than RTHUs from 15 October through 15 March. Please be sure to report any of these "unusual" and "vagrant" hummingbirds directly to research@hiltonpond.org as soon as possible after sighting.

Comments:

Ruby-throated Hummingbird (RTHU)

Flower Visit Protocol Data Sheet

School Name: ______________________Class or Group Name: __________________________

Name(s) of Student(s) Filling in *Data Sheet:* ____

____

Site Name: ____

	NUMBER OF FLOWER VISITS					
Date						
Observation Start Time: (local time)						
Observation End Time: (local time)						
Observation Start Time: (UT)						
Observation End Time: (UT)						
Adult Male *full red throat* February-October (U.S., Canada) January-September ONLY (Mexico, Central America, Caribbean)						
Adult Male (probable adult, but may be an advanced juvenile) *full red throat* October-December (Mexico, Central America, Caribbean)						
Adult Female *white throat* February-April ONLY (U.S., Canada) January-May (Mexico, Central America, Caribbean)						
Undetermined Sex and Age (could be female or young male) *white throat* May-October (U.S., Canada) August-December ONLY (Mexico, Central America, Caribbean)						
Undetermined Sex and Age *throat not observed* Any time of the year (all locations)						
Young Male *throat streaked in green or black and/or one or more red throat feathers* May-October (U.S., Canada) August-April (Mexico, Central America, Caribbean)						

Observations are made in 45-minute time blocks. If no hummingbirds are seen, record “0” on the Data Sheet above and enter “0” on the data entry page on the GLOBE Web site.

For any “unusual” RTHU (i.e., one with “abnormal” plumage or one that is color-marked) record in the Data Entry page’s Comments section the color of the bird’s forehead, crown, throat, breast, belly, flanks, back, tail, bill, and eyes, and the location of other distinct markings. Describe the bird’s activity (including feeding behavior). Take a photo if possible. Also follow this procedure for any “vagrant” hummingbirds other than RTHUs from 15 October through 15 March. Please be sure to report any of these “unusual” and “vagrant” hummingbirds directly to research@hiltonpond.org as soon as possible after sighting.

Comments:

Ruby-throated Hummingbird (RTHU)

Feeder vs. Flower Visit Protocol Data Sheet

School Name: ______________________Class or Group Name: __________________________

Name(s) of Student(s) Filling in *Data Sheet:* ____

____

Site Name: ____

	NUMBER OF VISITS					
Date						
Observation Start Time: (local time)						
Observation End Time: (local time)						
Observation Start Time: (UT)						
Observation End Time: (UT)						
Adult Male *full red throat* February-October (U.S., Canada) January-September ONLY (Mexico, Central America, Caribbean)	Feeder:					
	Flower:					
Adult Male (probable adult, but may be an advanced juvenile) *full red throat* October-December (Mexico, Central America, Caribbean)	Feeder:					
	Flower:					
Adult Female *white throat* February-April ONLY (U.S., Canada) January-May (Mexico, Central America, Caribbean)	Feeder:					
	Flower:					
Undetermined Sex and Age (could be female or young male) *white throat* May-October (U.S., Canada) August-December ONLY (Mexico, Central America, Caribbean)	Feeder:					
	Flower:					
Undetermined Sex and Age *throat not observed* Any time of the year (all locations)	Feeder:					
	Flower:					
Young Male *throat streaked in green or black and/or one or more red throat feathers* May-October (U.S., Canada) August-April (Mexico, Central America, Caribbean)	Feeder:					
	Flower:					

Observations are made in 45-minute time blocks. If no hummingbirds are seen, record “0” on the Data Sheet above and enter “0” on the data entry page on the GLOBE Web site.

For any "unusual" RTHU (i.e., one with "abnormal" plumage or one that is color-marked) record in the Data Entry page's Comments section the color of the bird's forehead, crown, throat, breast, belly, flanks, back, tail, bill, and eyes, and the location of other distinct markings. Describe the bird's activity (including feeding behavior). Take a photo if possible. Also follow this procedure for any "vagrant" hummingbirds other than RTHUs from 15 October through 15 March. Please be sure to report any of these "unusual" and "vagrant" hummingbirds directly to research@hiltonpond.org as soon as possible after sighting.

Comments:

Ruby-throated Hummingbird (RTHU)

Flower Species Visit Protocol Data Sheet

School Name: ______________________Class or Group Name: __________________________

Name(s) of Student(s) Filling in *Data Sheet:* ____

____

Site Name: ____

Date						
Observation Start Time: (local time)						
Observation End Time: (local time)						
Observation Start Time: (UT)						
Observation End Time: (UT)						
FLOWER NAME	**NUMBER OF FLOWER VISITS, by Species**					
Genus:						
Species:						
Adult Male *full red throat* February-October (U.S., Canada) January-September ONLY (Mexico, Central America, Caribbean)						
Adult Male (probable adult, but may be an advanced juvenile) *full red throat* October-December (Mexico, Central America, Caribbean)						
Adult Female *white throat* February-April ONLY (U.S., Canada) January-May (Mexico, Central America, Caribbean)						
Undetermined Sex and Age (could be female or young male) *white throat* May-October (U.S., Canada) August-December ONLY (Mexico, Central America, Caribbean)						
Undetermined Sex and Age *throat not observed* Any time of the year (all locations)						
Young Male *throat streaked in green or black and/or one or more red throat feathers* May-October (U.S., Canada) August-April (Mexico, Central America, Caribbean)						

Observations are made in 45-minute time blocks. If no hummingbirds are seen, record “0” on the Data Sheet above and enter “0” on the data entry page on the GLOBE Web site.

For any “unusual” RTHU (i.e., one with “abnormal” plumage or one that is color-marked) record in the Data Entry page’s Comments section the color of the bird’s forehead, crown, throat, breast, belly, flanks, back, tail, bill, and eyes, and the location of other distinct markings. Describe the bird’s activity (including feeding behavior). Take a photo if possible. Also follow this procedure for any “vagrant” hummingbirds other than RTHUs from 15 October through 15 March. Please be sure to report any of these “unusual” and “vagrant” hummingbirds directly to research@hiltonpond.org as soon as possible after sighting.

Comments:

Ruby-throated Hummingbird (RTHU)

Nesting Report Protocol Data Sheet (U.S. and Canada)

School Name: ______________________________

Class or Group Name: ______________________________

Name(s) of Student(s) Filling in *Data Sheet:* ______________________________

____

Site Name: ______________________________

Date Nest Was Found: ______________

Check One:
- ☐ 1st set of eggs at this nest
- ☐ 2nd set of eggs at this nest
- ☐ 3rd set of eggs at this nest

Record dates for the following observations. It is possible you will not observe all activities listed.

Observation	**Date**
Start of Nest Construction	
End of Nest Construction	
First Sighting of Adult Female on Nest	
Laying of First Egg	
Laying of Second Egg	
First Egg Hatched	
Second Egg Hatched	
When First Nestling Leaves the Nest	
When Second Nestling Leaves the Nest	
Last Sighting of Adult Female on Nest	

Number of eggs laid: ______________

Number of eggs that did not hatch: ______________

Number of nestlings that survived: ______________

Record dates and observations of adult male RTHU behavior at the nest: ______________

____

____

____

Comments: ______________________________

____

____

____

Clonal and Common Lilac
Site Definition Sheet

School Name: ______________________________ Class or Group Name: ________________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: __________________________

Site name (give your site a unique name): ____

Coordinates: Latitude: ____________________ ❒ N or ❒ S (check one)
Longitude: ____________________ ❒ E or ❒ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❒ GPS ❒ Other

If other, describe: ____

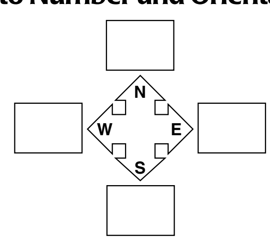
Nearest Atmosphere Site: ATM-______

Distance to Site: ____ meters; Direction to Site: ❒ N ❒ NE ❒ E ❒ SE ❒ S ❒ SW ❒ W ❒ NW

Elevation Difference (Atmosphere Site – this site): _______ meters (this value may be positive or negative)

Lilac shrub label	**Clonal or common**	**Date planted OR indicate if planted before 1997**	**Height (cm)**

Photo Number and Orientation



Comments: ____

____

____

____

____

____

Common and Clonal Lilac

Data Sheet

School Name: ____________________Class or Group Name:__________________________________

Name(s) of student(s) filling in Data Sheet:____

____

Site Name:____

Lilac shrub label	Clonal or common	Date of first leaf observed (YYYY/MM/DD)	Date of last observation immediately before first leaf (YYYY/MM/DD)	Date of full or 95% leafed (YYYY/MM/DD)	Date of last observation immediately before full leaf (YYYY/MM/DD)

Lilac shrub label	Clonal or common	Date of first bloom observed (YYYY/MM/DD)	Date of last observation immediately before first bloom(YYYY/MM/DD)	Date of full bloom (YYYY/MM/DD)	Date of last observation immediately before full bloom (YYYY/MM/DD)

Lilac shrub label	Clonal or common	Date of fend of bloom (YYYY/MM/DD)	Date of last observation immediately before end of bloom(YYYY/MM/DD)	Height (cm) Measured once only in autumn

Comments:____

____

____

____

____

____

____

Phenological Gardens

Site Definition Data Sheet

School Name: ______________________________Class or Group Name:______________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: __________________________

Site name (give your site a unique name):____

Coordinates: Latitude: __________________ ❐ N or ❐ S (check one)
Longitude: ____________________ ❐ E or ❐ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❐ GPS ❐ Other

If other, describe:____

Nearest Atmosphere Site: ATM-______

Distance to ATM Site: ____ meters;
Direction to Site: ❐ N ❐ NE ❐ E ❐ SE ❐ S ❐ SW ❐ W ❐ NW

Elevation Difference (Atmosphere Site – this site):_______ meters (this value may be positive or negative)

Nearest Soil Moisture Site: SMS-_____

Distance to Soil Moisture Site:______(meters);
Direction to Site: ❑ N ❑ NE ❑ E ❑ SE ❑ S ❑ SW ❑ W ❑ NW

Elevation Difference (Atmosphere Site – this site):_______ meters (this value may be positive or negative)

Plants in Garden

Shrub	**Planted in Garden? Yes or No**	**Date planted**
Witch Hazel 'Jelena'		
Witch Hazel 'Genuine'		
Lilac		
Mock-Orange		
Forsythia		
Heather 'Allegro'		
Heather 'Long White'		
Snowdrops		

Soil Texture in the top 10 cm (from *Soil Characterization Field Measurement Protocol*): _____________Soil pH in the top 10 cm (from *Soil Characterization Lab Analysis Protocol*): _______________________

Soil pH method (check one): ❑ paper ❑ meter

Photo Number and Orientation

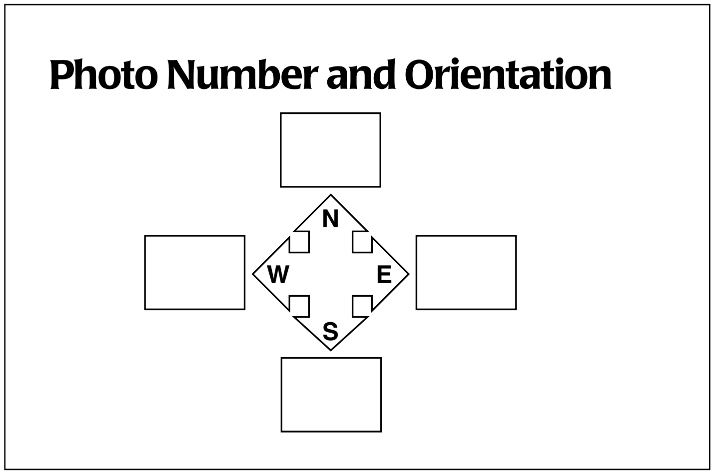


Photo of Garden

Comments (Metadata): ____

Phenological Gardens

Data Sheet

School Name: ____________________Class or Group Name:___________________________________

Name(s) of student(s) filling in Data Sheet:____

____

Site Name:____

For witch hazel, mock-orange, heather and snowdrops, record the dates for the following flowering stages:

	Flowering Stage		
Shrub	**BF**	**GF**	**EF**
Witch Hazel 'Jelena'			
Snowdrops			
Mock-Orange			
Heather 'Allegro'			
Heather 'Long White'			
Witch Hazel 'Genuine'			

BF = Beginning of flowering

GF = General flowering

EF = End of flowering

For lilac and forsythia, record the dates for the following flowering and leaf growth stages:

	Flowering Stage			Leaf Stage	
Shrub	**BF**	**GF**	**EF**	**LU**	**FL**
Lilac					
Forsythia					

LU = Beginning of leaf unfolding

FL = Full leafs

Height and health of each plant. Measure in the Autumn.

Shrub	**Height (cm)**	**Health of Shrub** **Healthy = H** **Unhealthy = U** **Dead = D**	**If shrub died, did you replace it with another shrub? (yes or no)**
Witch Hazel 'Jelena'			
Snowdrops	not necessary to measure the height		
Mock-Orange			
Heather 'Allegro'			
Heather 'LongWhite'			
Lilac			
Forsythia			

Was fertilizer used on the plants this year?________ If yes, date of application: ________________

Type of fertilizer ____________________

Record dates plant(s) were watered:____________________

If plants are pruned, record date(s):____________________

Comments (Metadata): ____

____

____

____

____

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____

Seaweed Reproductive Phenology

Site Definition Data Sheet

School Name: ______________________________ Class or Group Name: ______________________

Name(s) of student(s) filling in *Data Sheet:* ____

____

Date: __________________________

Site name (give your site a unique name): ____

Coordinates: Latitude: ____________________ ❒ N or ❒ S (check one)
Longitude: ____________________ ❒ E or ❒ W (check one)
Elevation: _____ meters

Source of Location Data (check one): ❒ GPS ❒ Other

If other, describe: ____

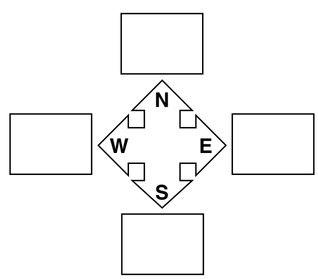
Tidal Range: _________ meters

Beach Aspect: __________°

Beach Slope: __________°

Dominant Rock size (check one): ❑ large boulders ❑ medium boulders
❑ small boulders ❑ cobbles ❑ pebbles ❑ gravel

Photo Number and Orientation



Comments (Metadata): ____

____

____

____

____

____

Seaweed Reproduction Phenology Protocol
Data Sheet

School Name: ____________________Class or Group Name:_________________________

Name(s) of student(s) filling in *Data Sheet:*____

____

Site Name:____

Date: _____________________

Time:_____________(local) ________(UT)

Time of low tide:_____(local) _________(UT)

Species (check one): ❑ *Fucus vesiculosus* ❑ *Asophyllum nodosum*

❑ *Fucus distichus* ❑ *Fucus spiralis* ❑ *Fucus serratus*

❑ *Pelvetia canaliculata*

Stage	**1**	**2**	**3**	**4**	**5**	**Total**
Number of receptacles in Stage						
Percentage of receptacles in stage [(number in stage/total number of receptacles observed)*100]						100

Comments: ____

____

____

____

____

____

Arctic Bird Migration Monitoring

Site Definition Data Sheet

School Name: ______________________________ Class or Group Name: ______________________

Name(s) of student(s) filling in Data Sheet: ____

____

Date: __________________________

Site name (give your site a unique name): ____

Coordinates: Latitude: ____________________ ❐ N or ❐ S (check one)
Longitude: ____________________ ❐ E or ❐ W (check one)
Elevation: _____ meters

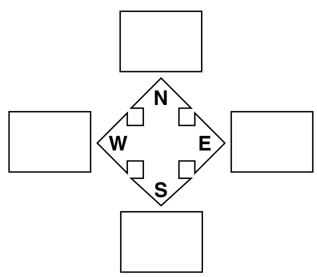
Source of Location Data (check one): ❐ GPS ❐ Other

If other, describe: ____

Nearest Atmosphere Site: ATM-______

Distance to ATM Site: ____ meters;
Direction to Site: ❐ N ❐ NE ❐ E ❐ SE ❐ S ❐ SW ❐ W ❐ NW

Photo Number and Orientation



Type of Site (select one): ❐ Field ❐ Estuary/shore ❐ Lake or Pond ❐ Ocean/shore
❐ Forest or Woodland ❐ Other

If other, describe: ____

Comments (Metadata): ____

____

____

____

____

____

____

____

Arctic Bird Migration Monitoring Protocol

Data Sheet

School Name: ______________________________ Class or Group Name: ______________________

Name(s) of student(s) filling in Data Sheet: ____

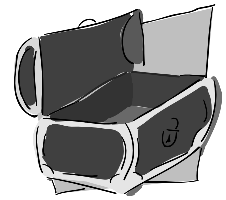
Site name: ____

Bird Genus: __________________ Species: ___________________ Bird species common name: ________________________________

Bird Observations

Date	Local Start Time	Local End Time	Start Time (UT)	End Time (UT)	If by ocean, UT time of low tide	Number of birds	Comments

Glossary



Abscission
Separation of leaves or other structures from an axis by the formation of an layer that reduces and then cuts off the flow of water and nutrients between leaf and tree

Acclimation
Process by which plants become increasingly resistant to subfreezing temperature without sustaining injury.

Adhesion
Molecular attraction that holds the surfaces of two substances together e.g. attraction of water molecules to other kinds of molecules

Aerosols
Particles of solid and liquid suspended in the atmosphere

Almost Closed System
A system in which almost no matter enters or leaves; the Earth system is considered an almost closed system because only a small amount of gases and particles enter or leave the system at the top of the atmosphere. In studying the Earth as a whole you use

Annotate
To label

Anthocyanin
Pigment in leaves that is bright red and purple

Aquifer
A body of permeable rock or gravel capable of storing water underground

Atmospheric Carbon
Carbon that is in gaseous form (combined with other atoms like oxygen) that make up part of the Earth's atmosphere such as carbon dioxide and carbon monoxide

Average Surface Temperature
The surface temperature of the Earth averaged over a wide region and over a long period of time

AVHRR Satellite
Satellite that carries the Advanced Very High Resolution Radiometer instrument

Axis
The invisible straight line between the North and South poles

Biogeochemical Cycles
Movement of chemical elements from organisms to physical environment back to organisms in a circular cycle

Biomass
Total mass of all the organisms of a given type or in an area or region

Biome
A major ecological community type (e.g., rain forest, grassland, desert)

Biota
All of the organisms living in a particular region, including plants, animals, and microorganisms

Boreal
Of or relating to northern regions or the Northern Hemisphere

Boundary
A line or a plane that divides two different areas or regions

Broad-leafed Trees
Trees that have wide and flat leaves rather than needlelike leaves

Budburst
The opening or breaking of buds which are hard protective covers containing miniature leaves. It is a seasonal event that signals the start of leaf growth or green-up

Canopy
The uppermost layer of plant leaves that are detected by satellite remote sensing

Capillary Action
Attraction of the surface of a liquid to the surface of a solid which is expressed as the readiness of a liquid such as water, to flow through a solid such as paper

Carbon Cycle
The movement of carbon through the surface, interior, and atmosphere of the Earth, which may involve organisms

Carbon Fixation
The process by which carbon taken from the carbon dioxide in the air is incorporated in the cells of a plant or microorganism, such as in photosynthesis

Carotene
Pigment in leaves that is orange

Celestial Sphere
An imaginary sphere of infinite extent with the Earth at its center on which the stars, planets, and other heavenly bodies appear to be located

Chemical Cycle
The movement of various chemicals through the surface, interior, and atmosphere of the Earth and the chemical reactions that impact the form of those chemicals

Chemical Energy
The energy produced or absorbed in the process of a chemical reaction

Chlorophyll
A pigment which gives plants their green color and traps light energy for plants, algae, and some bacteria to use in making food

Chromatography
The separation of substances in a mixture by placing the mixture in a mobile phase (water or other solvent) that is placed over a stationary phase (e.g. paper)

Climate
The statistical collective of the weather conditions of a specified area during a specified time period

Climate Cycles
Alternating episodic climate events that recur with some regularity, but are not strictly periodic

Climatic Island
An area of uniform climate, such as a mountain top, that is isolated from other areas similar to it

Climatogram
A graph showing the long term average of temperature and precipitation totals for a region (a year or longer)

Climatograph
See climatogram

Closed System
A system in which no matter enters or leaves

Cohesion
Force holding a solid or liquid together due to the attraction of like molecules, for example the attraction of water molecules to each other

Components
Parts of a whole

Conifers/Coniferous
Any cone-bearing trees, chiefly evergreen trees of the class Coniferinae, including pine, fir, and spruce that have needle-like leaves

Connections
Links between one component of the Earth system and another

Consumers
Living things that use resources in their environment to survive

Continental Climate
Climate characteristic of the interior of a large land mass, generally marked by large annual and daily ranges of temperature, low relative humidity and generally moderate or small amounts of rainfall.

Contrast
The ratio between maximum and minimum values

Control
An experimental set up and result against which other experiments that incorporate modifications or changes and the results of those experiments are compared

Crown
The leafy portion of a tree or shrub. Even the lowest branches of a tree or shrub are part of the crown

Cryosphere
Part of the Earth that is frozen, comprising ice sheets, glaciers, and sea areas covered by ice

Dew Point
The temperature to which air must be cooled to reach saturation of water vapor to occur

Diagram
A visual representation of a system used to communicate information about that system to others

Diurnal
Daily, as in diurnal rotation of the Earth

Dormancy
State of suspended growth and metabolism

Earth System
The components that comprise the environment of the Earth, including the atmosphere, hydrosphere, lithosphere, pedosphere (soils), cryosphere (ice), and biosphere, and the processes that cause them to interact

Earth System Science
An area of scientific investigation that focuses on the processes which take place in the atmosphere, hydrosphere, lithosphere, pedosphere (soils), cryosphere (ice), and biosphere and the processes that allow them to interact.

Ecliptic
Where the Earth's orbit intersects the celestial sphere

Ecologist
A scientist who studies the relations between organisms and their environment

Ecology
The study of the relations between organisms and their environment

Ecosystem
A local biological community and its pattern of interaction with its environment

Elevation
The vertical distance above mean sea level

Energy Cycle
The movement of energy through the surface, interior, and atmosphere of the Earth in all of its forms

Environment
The surrounding conditions that affect the quality of life of plants and animals

Environmental variables
Physical properties that describe the state of the environment

Equator
An invisible circle that divides the Earth into two hemispheres

Equatorial
Located at the equator or in the plane of the equator

Equinox
(equal night) when the sun crosses the equator, causing the length of day and night to be equal in both hemispheres

Estuary
Semi-inclosed coastal body of water which has a free connection with the open sea

Flux
The amount of material flowing through a specified surface or system per unit time

Fluxes
The rate of flow of some quantity (such as water, energy or carbon for example) from one place or reservoir to another

Frazzle Ice
Known also as frazil ice, flowing water ice that forms platelets rather than continuous sheets on rivers and other moving bodies of water

GIS
Geographic Information System

Grassland
An area of natural vegetation dominated by grasses (areas are called steppes or prairies in temperate regions and savannahs in tropical regions)

Green-down
When plants start changing colors and/or lose their leaves at the end of the growing season

Green-up
When plants sprout new growth

Grey-scale
A range of tones from white to black that indicate on a map or other visualization the relative amounts of the quantity being described

Growing Season
That part of the yearly plant growth cycle when vegetation comes out of winter dormancy, grows, and reproduces.

Hemisphere
Half of a spherical or roughly spherical body (such as the Earth)

Icosahedron
20-sided polyhedron

Insolation
The energy that comes to the Earth from the Sun (INcoming SOLar radiATION)

Interconnections
The processes by which the different components of the Earth system interact with each other

Kinetic Energy
The energy an object has because of its motion

Land Cover
Usually vegetation but in the absence of vegetation an indication of what is on the land surface

Landmark Value
The point on a color scale where the representative value undergoes a distinctive change

Latent Heat
The energy stored or used by a substance to produce a change in phase, either between solid and liquid, liquid and gas, or solid and gas

Latitude
The angular distance of a part of the Earth that is north or south of the Earth's equator; a region of the Earth considered in relation to its distance from the equator

Lichen
A combination of an alga (or a cyanobacterium) and a fungus, living in symbiotic relationship characteristically forming a crustlike, scaly or branching growth on rocks or tree trunks

Limiting Factor
An ecosystem variable whose presence or absence limits the growth of the ecosystem elements

Lithosphere
The solid portion of the Earth

Liverwort
Moss-like plants that grow and help decay rocks or tree trunks on damp ground

Longitude
Distance measurement that goes from one pole to another pole around the outside of the Earth

Map Projection
The systematic arrangement of latitudes and longitudes (and associated surface features) that shows a curved surface on a flat plane

Marine Climate
Climate of a region that is affected by the sea. Generally characterized by mild winters, cool summers, and an even distribution of rainfall through the year

Maxima
(Plural of maximum) the greatest possible amount or degree

Maximum Greenness
When vegetation vigor peaks

Mercator Projection
A map projection of the Earth in which the latitude lines are drawn as straight lines the same length as the equator and cross the longitude lines at right angles. The biggest disadvantage is the distortion of the land near the poles

Meridian
An imaginary circle on the Earth's surface that passes through the North and South poles

Mid-latitude
The latitude range generally between 30 degrees to 60 degrees

NDVI
Normalized Difference Vegetation Index

Nitrogen Cycle
A series of chemical processes, mostly occurring in organisms, in which nitrogen atoms are circulated in the Earth systems

NOAA
National Oceanographic and Atmospheric Administration

Northern Hemisphere
The half of the Earth that lies north of the equator

Ocean Currents
The movement of ocean water in a regular way along a defined path that can either be cyclic or continuous

Open System
A system in which mass and energy enter and leave

Ozone
One of the allotropes of oxygen (O3), sometimes referred to as tri-oxygen

Perpendicular
A line at right angles to a line or plane (for example, when you watch a sunset, you are standing perpendicular to the horizon)

Petiole
Slender stem that supports the leaf or leaf stalk

pH
A measure of acidity on a scale of 0 to 14, 0 being all hydrogen ion (highly acidic), 14 being no hydrogen, all hydroxyl ions (highly basic)

Phenology
The study of natural response of living organisms to seasonal and climatic changes in their environment. Examples of phenological events include migration of birds and butterflies, flowering, salmon spawning, etc. Plant phenology includes green-up and green-down

Photosynthesis
The process used by green plants, algae and photosynthetic bacteria to use the energy of sunlight to convert carbon dioxide and water into carbohydrates, through the green pigment chlorophyll; this process releases oxygen and is the chief source of atmosphere

Polar
Regions on the Earth poleward of 60 degrees latitude

Polyhedron
A solid formed or bounded by planes or faces

Potential Energy
The energy an object has or the objects' stored capacity to do work because of its configuration and position

Potential Growing Season
That part of the yearly temperature cycle when the temperature is above freezing, thus enabling plant growth to occur.

Processes
The progression of physical interactions between different components of the Earth system and between sub-components of the Earth system

Producers
Living things that as a result of their biologic processes release material into their environment that may be used by other living things

Protractor
A measuring device used to measure angles

Region
An area defined by a common feature or features

Relationships
Processes by which different components of the Earth system, or parts of the components of the Earth system interact and affect each other

Remote Sensing
A method of obtaining information about something without coming into physical contact with it

Reservoirs
A space to store a substance, or a supply of a substance

Resolution
The smallest area that can be identified individually in a map or satellite picture, or the smallest measurable change in a quantity

Respiration
A process by organisms that converts the energy in organic materials into energy for use by cells

Rural
An area with very little man made structures

Satellite
Any natural or man made object that orbits an body in space, man made satellites usually carry instruments for measuring various things about the Earth

Scale
The regular markings on an instrument that permit the readings of a measured quantity, or the relative size of an object or area used to help define the processes that affect that object or area

Seasonal Cycle
The regular progression through the year through winter, spring, summer, and fall

Senescence
The changes that occur in an organism between maturity and death; in a plant this is equivalent to "green-down" and is associated with a reduction and/or halt of plant photosynthesis

Sensible Heat
The energy involved in heating (or cooling in the case of a loss of sensible heat) of a surface or object

Solar Energy
Energy coming from the sun

Solstice
(Stand still) when the sun is at its greatest distance from the equator, resulting in the longest day in one hemisphere and the shortest day in the other hemisphere; the sun appears to "stand still" when it reaches its highest point on this day

Southern Hemisphere
The half of the Earth that lies south of the equator

Spatial Relationship
Where bodies are located in regards to each other (e.g., the Sun and the Earth)

Sub Polar
A climate zone lying between the temperate and polar zones

Sub Tropical
A climate zone lying between the tropic and temperature zones

Suburban
An land area in which there is a mixture of man-made structures and open spaces

Surface Temperature
The temperature of the surface or the air next to the surface of the Earth

System
A group of components that interact to produce a whole (in the case of the Earth system) or a specific results (in the case of a machine)

Tannin
Bitter waste product in leaves that is brown; common name for tannic acid or similar compounds

Temperature
A measure of the energy in an object or gas, measured with a thermometer

Thermal inertia
A material body's resistance to a change in temperature

Time Scales
The time period over which different processes occur ranging from seconds and minutes for the formation of clouds to billions of years for the formation of the Earth

Transpiration
Loss of water by plants mainly through the stomata to the atmosphere

Tropic of Cancer
The parallel of latitude 23° 27' north of the equator; the most northerly latitude at which the sun can shine directly overhead

Tropic of Capricorn
The parallel of latitude 23° 27' south of the equator; the most southerly latitude at which the sun can shine directly overhead

Tropical
Of, occurring in, or characteristic of the tropics

Tundra
Treeless plains that lie poleward of the tree line in the Arctic. Tundra lies mostly over permafrost and is not permanently covered with snow

Urban
Area mostly covered with man made structures

Variables
A characteristic that can be measured and can assume different values

Vegetation Vigor
Amount of plant growth

Visualization
Display of information graphically or on a map using color or grey-scales, and/or lines and symbols

Water Cycle
The cycle by which water is moved between the different components of the Earth system (atmosphere, hydrosphere, lithosphere, pedosphere, cryosphere, and biosphere) in its various states (solid, liquid, and gas)

Watershed
The total area from which water is drained by a river and its tributaries

Weather
The day to day state of the atmosphere, mainly with respect to its affect on life and human activities

Winds
The movement of air relative to the surface of the Earth

Xanthrophyll
Pigment in leaves that is yellow